AËRIAL NAVIGATION

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FIG. 105. AËROSTAT ROUNDING THE EIFFEL TOWER (p. 146).

AËRIAL NAVIGATION

A PRACTICAL HANDBOOK

ON THE CONSTRUCTION OF DIRIGIBLE BALLOONS,

AËROSTATS, AËROPLANES, AND AËROMOTORS

BY

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With about One Hundred Illustrations

Capio Lumen

LONDON

CROSBY LOCKWOOD AND SON

7 STATIONERS' HALL COURT, LUDGATE HILL

1902

Printed at THE DARIEN PRESS *Edinburgh.*

PREFACE.

THE practical development of aërial navigation is slow relatively to other modes of locomotion. The chief cause lies in the fact that any disaster is nearly sure to be fatal to human life, and although ocean navigation is attended by a certain amount of danger to both life and property, the risk is minimised by the adaptability of boats, lifebuoys, and a considerable portion of the *débris* incidental to shipwrecks, to float upon the surface of the water and sustain the survivors. It is true that in many cases, in the present stage of rapid ocean transit, such life-saving appliances are not always available or successful, but the existence of them engenders a degree of confidence which has as yet no counterpart in aërial navigation.

There have been disasters in this enterprise—as there always will be, to the end of time, whenever man seeks to conquer the unknown. In olden times, when to the adventurous Phœnician navigator the unknown waste beyond the Pillars of Hercules was the edge of a veritable Plutonian abyss, men went forth and returned no more. And the wise City Fathers at the gates of Tyre prophesied this and that sad fate to the blasphemous seeker of the secrets of the gods. How many

stark ribs and frames of erstwhile stout galleys strewed the Ionian coasts ere the Pillars were won and the far-off Casseritides reached. No Lloyd's agencies, no shipping news, then existed to supply the record; but we may feel assured that the City Fathers expressed no astonishment, but accepted the fact literally when once accomplished. The ocean greyhound is now an every-day sight, and the air-ship will soon cease to cause astonishment.

Since recent successful experiments and commercial enterprise have combined to render aërial navigation a prominent feature in progressive science, no apology is needed in introducing the present volume, which treats of the laws governing flight as exemplified by animals, birds, and insects, and of the construction of dirigible balloons, aërostats, aëroplanes, and aëromotors to be synthetically deduced therefrom and illustrated by various types already made.

We admit the air-ship in practice to combine the aërostat, aëroplane, and mechanical propeller, and to be absolutely safe, but the exact proportions each must bear to the others is not within the province of a work the aim of which is to convey elementary instruction in a popular manner; and this also applies to the aëroplane, the term here being applied in a broad sense. When the area of the plane is subdivided into aërocurves, or reactionary surfaces of which the curvilinear construction is based upon the cissoid curve, the elaborate calculations governing this would be out of place. And in a similar manner we do not go into the intricate problems relating to the screw propeller in air, and its

reaction upon curved aëroplanes, but have endeavoured to present in readable fashion a thoroughly practical basis upon which the air-ship may be constructed and understood in its action.

From a commercial point of view the advantages to be derived from any increased speed due to aërial navigation as against other modes of locomotion are not immediately apparent, except for light postal services. The aëromotor or air-ship will always be of great value in naval and military tactics, and for Ordnance surveying purposes, still with exactly the same effect that applies to seagoing navies and war-craft generally—that is, each Power, whilst proceeding upon the defined primary lines of construction, will strive to possess the best aërial navy, and this spirit of competition will be good for inventors and for commerce generally. Aërial navigation can only effect a revolution in international matters by the discovery and application of the neutralisation and regulation of the force of gravity. Given this as a secret under the control of a peaceful and highly civilised Power, and war and its concomitant horrors would be a story of the past.

The true co-ordination of physical phenomena brings creative imagination to bear upon the dead side of the world turned to us, and causes us to comprehend the pulsations of its real life beyond the screen of materialism. So co-ordinates light, electricity, magnetism, and each new imaginative construction brings us nearer to the conception of a living universe. As an instance, we may take the now well-known "cathode rays," where force takes material embodiment, and we see that all apparently

quiescent matter is really energy at work in various forms; and again, there are the hitherto undeveloped mysteries of radiation.

The attraction of gravitation up to the present time has not co-ordinated with other forces, and there may yet be a mode of applying known forces in aërostation in this wide and all but untrodden field of research.

FREDK. WALKER.

OXFORD, *2nd June* 1902.

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AËRIAL NAVIGATION.

CHAPTER I.

THE LAWS OF FLIGHT.

Fundamental Laws.—There is a certain condition of moving bodies which affords a general measure of their force. When a moving body is directly opposed by a *vis mortua*, such as a pressure or resistance like that of gravity, the measure of such *vis mortua* required to neutralise the force and bring the moving body to rest must form the basis of the measurement of the force. The problem to be assumed is, in measuring the said force, to consider in which of its different capacities is its effect to be measured. If the length of the line which the moving body describes against a uniform resistance be taken as the effect and measure of the force, the force is as the square of the velocity. Taking the resistance to be that exerted by gravity, the estimation of the force becomes definite, and is measured in terms of the square of the velocity. And a body in true flight must be capable of motion in both directions, against the air resistance in one case and gravity in the other, and the force must be continuous, as will be seen hereafter.

Natural Flight.—The method of rising and progressing in the air varies according to the requirements of the animal, bird, or insect provided by nature with

wings. Such birds as the condor (*Sacheramphus gryphus*) and the albatross (*Diomedea exulans*) are capable of extended flight, the former poising as it were in the air at an altitude of over 10,000 ft., and the latter following a ship for a thousand miles. The wing surface of these birds is oblique, so that a rapid horizontal movement is attained. This movement, being diagonal or spiral, as the case may be, carries the bird upwards, and when it drops, by partially closing its wings, it does so in a diagonal direction with great rapidity, acquiring such momentum as to carry it upwards again. And the

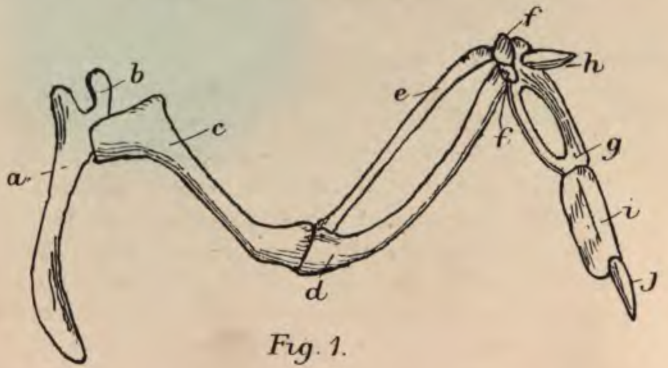

Fig. 1.

equipoise of the body is so sensitive, depending as it were on the fulcrum of the wings, that the long flight is maintained without an apparent flap. Soaring birds, such as the skylark, have the wings set horizontally when extended, in order to effect the upward flight in nearly a vertical direction.

The osseous framework of these wings is shown by Fig. 1. The *humerus c* articulates with a cavity between the *coracoid* bone *b* and the *scapula a*. It is directed backward in repose, approximately parallel with the spine. The *humerus* articulates at the opposite extremity with

the *cubitus* or forearm, which is composed of the *ulna d* and *radius e*, and is so jointed as to fold when at rest in a direction parallel to that of the *humerus*. The *carpus* consists of two small bones *f, f* placed between the outer extremity of the *cubitus* and the *metacarpus g*, which consists of two bones united at both ends. From the anterior edge of the *metacarpus* projects the *pollex h* and two digital bones or *phalanges i, j*. These latter are analogous to the fingers, and the *pollex* to the thumb of a

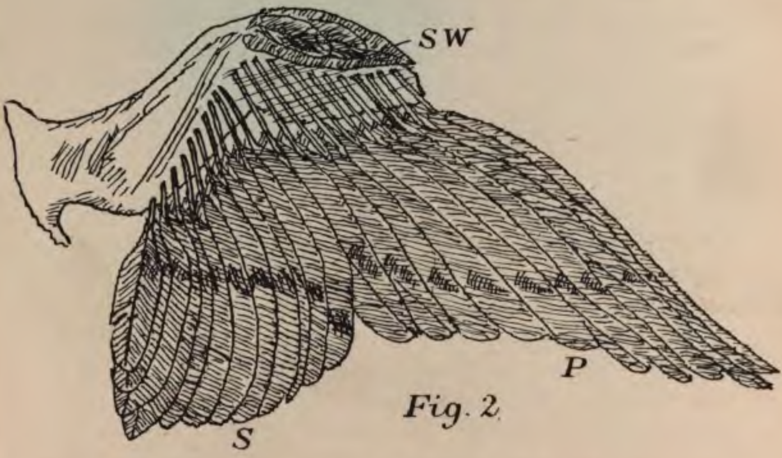

Fig. 2.

hand. The pectoral muscles operating the *humerus* are immensely powerful, extending from a deep *sternum* or breast bone, shaped like the keel of a ship. This qualifies the enormous expenditure of force which takes place when the body is not only supported but raised and propelled through the air. The bones of a bird are not only hollow, but in direct communication with the lungs, which admits of a constant supply of rarefied air, of less density than that surrounding it. Also the general structure affords the maximum of strength combined

with the minimum of weight. The skeleton of a condor measuring 6 ft. 4 in. over the tips of the wings, when newly articulated, and before the moisture had evaporated, was only 9.7 oz.

Referring to Fig. 2, the arrangement of the feathers is shown, the primaries P springing from the *digits i, j* and the *metacarpus g*, as shown by Fig. 1. The *secondaries* S take their origin from the *cubitus*, and the spurious wing or *alula* SW springs from the *pollex* or thumb. The expansion and contraction of the muscular system, in which the primaries and secondaries are held by their extremities, cause a semi-rotary movement to be imparted to each feather simultaneously with the movement imparted to the *humerus* by the pectoral muscles. In all cases the motion due to the action of the wings must be such that the air is struck with less force during the up-stroke than during the down-stroke; otherwise the effect of the former would neutralise that of the latter. Thus the semi-rotary movement of the feathers before-mentioned causes the surface of the wing to be altered upon the up-stroke, by turning the feathers so as to present the edges to the air, closing them to present a flat surface on the down-stroke. This is analogous to the movement called "feathering" in rowing, and also in using paddle wheels. Referring to the fundamental laws at the commencement of this chapter, it will be seen that the resistance varies as the square of the velocity of the stroke. Hence, if the down-stroke be made at three times the speed rate of the up-stroke, the resistance is nine times greater. But as this only operates during one-third of the time, it is in effect equal to three times that which operates against the up-stroke. Therefore the alteration of the effective area of the wing at each portion of the double stroke is essential to flight.

In the case of the flight of bats (*Vespertilio*) the

method of varying the surface area is necessarily different, since a soft membrane takes the place of feathers.

The general structure of a bat's wing is shown by Fig. 3. Here the *cubitus d* articulates with the *humerus c*, and carries the *phalanges i, j, k* and a hooked thumb *h*. The hinder legs *l* terminate in a single hooked phalange, and the tail *t* supports the caudal membrane, which by deflection enables the animal to steer its flight. The method of flight is to rise by flapping, the up-stroke

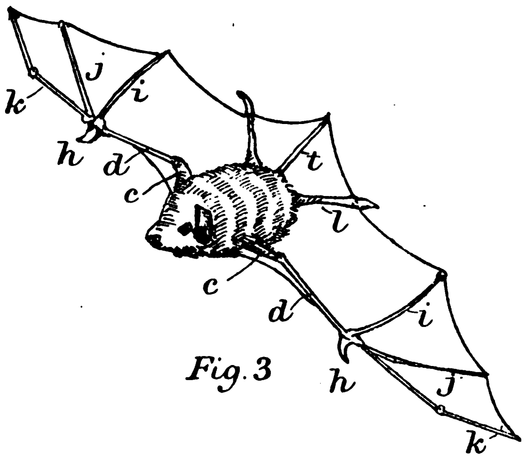

Fig. 3

being made with the wing surface diminished and the membrane slackened by partial closure of the *phalanges i, j, k*, in the same manner as in the case of the flight of birds. The bat swoops downwards with extended wings, fully stretched, and by a sudden deviation ascends again diagonally, impelled by the acquired momentum of the rapid ascent. Or the animal may fly in a spiral or curvilinear direction. The sense of equilibrium is highly developed, and the darting flight is sustained for hours without the necessity for alighting.

The pterodactyl, a huge flying lizard, now extinct, had wings of this description, and its method of flying was undoubtedly the same.

The flight of insects varies somewhat, and although the power is exerted in the same ratio relatively to resistance and velocity as in the cases before-mentioned,

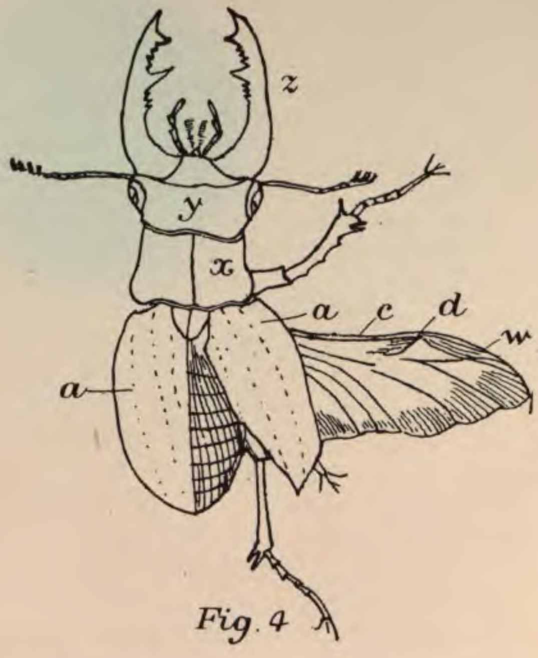

Fig. 4

the higher velocity of displacement of air alters the conditions. When a volume of air is displaced by a series of infinitely rapid vibrations, the wave effect is that of the waves given off from the striking surface of the wing at a high velocity and the incoming waves to fill the displacement at a less velocity. Air delivered at a high

velocity in this manner partakes of the attributes of a fluid under similar conditions, that is to say, it is sprayed or atomised, and to a certain extent, rarefied. This phenomenon is of importance when studying the flight of coleopterous insects.*

Fig. 4 shows the arrangement of the organs of flight of the common stag beetle (*Lucanus cervus*), in which the anterior wings or *elytra* are corneous in structure, presenting a convex outer surface and a concave inner surface. The *elytra a* form cases for protecting the membranaceous posterior wings *w* when closed and in repose, and the muscles of the thorax *x* merely allow of opening and closing, or remaining rigid in either position. The true wing is the posterior *w*, and consists of two layers of thin membrane, one superimposed above the other, and covering intersecting ribs or nervures, which form the framework and the source of vibratory motion. These nervures, which to the unassisted eye appear like threads, are of varying thicknesses, the thicker nervures passing horizontally through the wing, and the thinner ones intersecting them. The upper faces of the nervures are of a horny structure and adhere closely to the upper membrane, but the under surfaces are not so intimately attached to the under membrane, and are flattened. Thus the under membrane may be separated by skilful dissection for purposes of microscopic examination. These nervures are tubular in form, tapering toward the end or edge of the wing, and within them is disposed a spiral elastic tube, with the inner end communicating

* This theory of vibratory flight is due to M. Chabrier, and explained in his "Essai sur le Vol des Insectes," and carries a certain amount of probability, which has not, by reason of the extreme delicacy of such a mechanical test, been put to the proof of experiment. The subject is worthy of further research.

with the lungs, or an air vessel controlled by muscles so as to dilate or contract at the will of the insect. This spirally rolled tube constitutes a trachea. Thus the air is struck as it were by the flattened stretched surface at one period of the vibration and slackened at the other period. The terms up-stroke and down-stroke are not applicable to a vibrating surface which changes its direction and character many hundreds of times in a second of time. When we consider that the thorax *x*, *y* (comprising the prothorax, mesothorax, and metathorax) and the extended claws *z* are of considerable bulk, and also extend beyond the fulcrum of the wing *w*, it is idle to

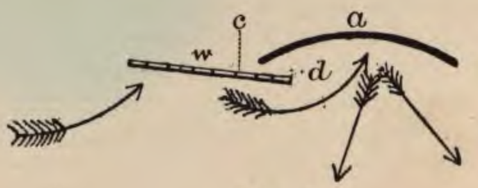

Fig. 5.

conceive that the anterior fixed wing or *elytra a* is not an organ of suspension, if not of flight. It will be seen that the outer nervure or *radius c* terminates in a branch *d*, the *stigma*, which forms a junction with the second nervature or *cubitus*. Since the *radius c* is thicker than the other nervatures, it forms with the stigma a cup or concavity approximately fitting the edge of the *elytra a*. Thus, referring to the diagram, Fig. 5, in which the wing *w* is tense, and vibrating downwards, the direction of the air currents diverted into *a* is shown by the arrows, and when the wing *w* is slackened at the other period of vibration, the cup formed by the junction of the *radius c* and *stigma d* approximately closes the posterior edge of

the *elytra a*. We have seen that air displaced at a high velocity is subject to rarefaction, and therefore is lighter than the surrounding air. These conditions enable the rigid *elytra* to support the projecting organs. Although the coleoptera are distinguished by a trunk of considerable bulk, it is owing to its membrano-cellular structure, of extreme lightness, and the organs for the diffusion of air, permeating the whole organic formation, render this type of insect capable of a tolerable range of flight.

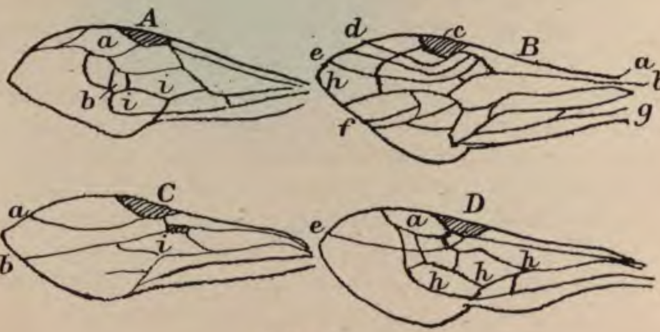

Fig.6.

The wings, and consequently the conditions of flight, vary according to the general shape and bulk of the types of insects, since, in the case of the hemiptera, the *elytra* are semi-corneous or coriaceous, forming a vibratory anterior wing, and at the same time, by reason of their leathery structure, constituting a sheath for the posterior wing, of membranous consistence. In the lepidoptera and hymenoptera the anterior and posterior wings are alike. Referring to Fig. 6, which shows the disposition of the nervures of the wings of hymenoptera, in B the *radius* or chief nervure *a* and the *cubital* nervure

b join to form the *stigma c*. These being the primitive nervures, other lesser nervures termed *brachial g*, spring from the thorax towards the extremity of the wing. In B a *radial* nervure *d* springs from the *stigma c* to the anterior edge, enclosing by an intersecting nervure a membranous space called the *radial cell a* (sketches A and C). *Cubital cells b* and *e* are similarly formed. The *brachial* nervures and their branches form *humeral* cells *h*, D, by intersection, and also *discoidal* cells *i*, A, C, and extensions of the *brachial nervures g* towards the posterior edge of the wing, starting from an intersecting nervure, are termed *recurrent* nervures *f*, B. Now the theory of flight in the case of such wings is upon the presumed alternation of dilation of the *radius* and *cubitus* together, and the *brachial* nervures together, thus forming a wave-like undulation of the surface from the anterior to the posterior edges of the wing at an approximately right angle to the longitudinal nervures. The progress of the insect during flight is, according to this theory, due to a rapid displacement of air in a given plane, the actions of rising and falling being effected by an alteration of the angle of the surface in the thoracic articulation. To describe the motion in plain language, it may be said that the wing surface rests upon a rapidly moving film of air rarefied by the velocity of impact, the rarefaction and movement being derived from the undulatory motion due to alternate dilations of the spiral internal nervures, the alternations being performed at a high velocity. In its proper place it may be shown how artificial flight may be mechanically produced in exactly the same manner.

The membranous skin uniting the fore and hind legs of the flying opossum (*Pataurus sciurus*) and other so-called flying animals, simply acts as an aëroplane or parachute enabling them to drop from a height and travel

across a certain space laterally whilst doing so. In the opposition of a wind current, ascension may be effected by angular steering assisted by the momentum acquired by the fall. Flying fish (*Exocetus*) are provided with extended pectoral fins which form aëroplanes, and enable them to skim from wave to wave.

CHAPTER II.

AËROSTATICS.

The Atmosphere.—The elastic medium called air forms a sheath as it were around the earth from 40 to 50 miles in thickness. Air being an elastic fluid, the particles thereof repel each other with a force varying inversely as the distance of the centre of the particles from each other. Therefore the volume and consequently the pressure depend upon each other. The law of altitudes and densities is as follows:—

Take the altitudes above the surface of the earth in arithmetical progression, the equivalent densities will be in geometrical progression decreasing.

Thus, if at a certain altitude above the earth's surface the density of the air be one-half that of the surface density, at twice the altitude the density will be one-fourth of the surface density. The height is measured in these terms by a barometer, which is constructed upon the basis that the atmosphere at sea level will support a column of mercury 30 in. in height at a normal temperature of 64° Fahr. This corresponds to a pressure of 14.72 lbs. per square inch. It is necessary to consider the barometer as an instrument for measuring the height above sea level, and also of external surface pressure. The usual form of barometer used is that known as "aneroid," the action of which depends upon the variation of external pressure upon an exhausted corrugated cylinder in which nearly a perfect vacuum has been formed. An index, reading inches of mercury,

feet in height above sea level, and pressure is delicately connected to the exhausted cylinder, which expands under decreased atmospheric pressure and indicates the degrees upon the dial. Air is sensitive to variations of temperature, and the barometrical readings have to be corrected accordingly.

At the sea level the air pressure is 2119.8 lbs. per square foot, and the following table shows the decrease at different altitudes :—

Barometer, Inches.	Altitude, Feet.	Pounds, Square Foot.	Barometer, Inches.	Altitude, Feet.	Pounds, Square Foot.
29.5	351	2091.0	20.0	10,593	1413.2
29.0	872	2055.7	19.5	11,254	1377.8
28.5	1,340	2013.7	19.0	11,933	1342.5
28.0	1,802	1978.4	18.5	12,630	1307.1
27.5	2,273	1943.1	18.0	13,346	1271.8
27.0	2,753	1907.8	17.5	14,082	1236.5
26.5	3,241	1872.4	17.0	14,839	1201.2
26.0	3,739	1837.1	16.5	15,619	1165.8
25.5	4,276	1811.8	16.0	16,423	1130.5
25.0	4,763	1776.5	15.5	17,252	1095.2
24.5	5,291	1731.1	15.0	18,109	1059.9
24.0	5,830	1695.8	14.5	18,995	1024.5
23.5	6,380	1600.4	14.0	19,911	989.2
23.0	6,942	1625.1	13.5	20,862	953.8
22.5	7,516	1559.8	13 0	21,847	918.5
22.0	8,103	1524.5	12.5	23,412	883.2
21.5	8,704	1519.1	12.0	23,874	847.9
21.0	9,319	1483.8	11.5	24,984	812.5
20.5	9,948	1448.5	11.0	26,142	777.2

The altitude may always be computed from the barometer readings according to the formula

$$4771 - b \times 6.000 \times t = \text{A}.$$

Where 4771 is 30 log. and b = log. of barometer reading in inches, t being the temperature correction according to the following table, and A the altitude in feet.

TABLE SHOWING VALUES OF t, DEGREE FAHR.

Degree Fahr.	t.	Degree Fahr.	t.	Degree Fahr.	t.	Degree Fahr.	t.	Degree Fahr.	t.	Degree Fahr.	t.
40	.973	64	1.000	88	1.027	112	1.053	136	1.080	160	1.106
42	.976	66	1.002	90	1.029	114	1.055	138	1.082	162	1.108
44	.978	68	1.004	92	1.031	116	1.057	140	1.084	164	1.111
46	.980	70	1.007	94	1.033	118	1.060	142	1.087	166	1.113
48	.982	72	1.009	96	1.036	120	1.062	144	1.089	168	1.115
50	.984	74	1.011	98	1.038	122	1.064	146	1.091	170	1.117
52	.987	76	1.013	100	1.040	124	1.066	148	1.093	172	1.120
54	.989	78	1.016	102	1.042	126	1.068	150	1.096	174	1.122
56	.991	80	1.018	104	1.044	128	1.070	152	1.098	176	1.124
58	.993	82	1.020	106	1.047	130	1.073	154	1.100	178	1.126
60	.996	84	1.022	108	1.049	132	1.076	156	1.102	180	1.129
62	.998	86	1.024	110	1.051	134	1.078	158	1.104	182	1.131

In this table t is determined by the sum of the lowest and highest barometrical readings. A further system for correcting inaccurate measuring is given in the tables for latitude, &c., in the Appendix.

Aerial Flotation.—A body immersed in air loses exactly in weight that of the volume of air displaced; therefore in dealing with such a body as an aërostat we have three distinct things to consider; *first*, the power of an aërostat to rise through the air; *second*, the velocity of its ascent; and *third*, the stability of its suspension at any given altitude, against the resist-

ance due to gravity. The aërostat, pure and simple, has an independent part to perform in all aëronautic machines, except the true aëroplanes and aëromotor planes, therefore it is worthy a detailed study. Since heated or rarefied air as a medium for filling an aërostat is not of practical utility in sustained flight of long duration, we will not occupy space with the matter, assuming hydrogen or carburetted hydrogen to be used.

Pure hydrogen (H) (atomic weight 1, density 1) is a colourless, odourless, tasteless gas, and is 14.43 times lighter than atmospheric air, consequently it is the best medium for filling aërostats. Coal gas or carburetted hydrogen is the next best, and varies according to the material used and the mode of its manufacture. This variation is such as to render the gas from 10 to 6 times lighter than air.

The force exerted in ascent is the excess of the weight of an equal bulk of atmospheric air above the aggregate weight of the included gas, plus the gas-tight envelope and all appendages; in other words the final power of ascent is the difference between the weight of the included gas and of that of an equal volume of external air, further diminished by the weight of the whole apparatus. Supposing the form of the aërostat to be the same in all cases, this load, as a resistance, as it depends upon the quantity of surface contained in the bag or envelope, must be proportioned to the *square* of the diameter; whereas the difference between the internal or external fluids, which constitutes the whole of the buoyant force, increases with the capacity of the envelope, the proportionate ratio to the *cube* of the diameter. Therefore it is obvious that however small the excess may be of the specific gravity of the external air above that of the included fluid, there must always exist some corresponding dimension which would

enable an aërostat to mount in the atmosphere. Aërostats are usually constructed to present a spherical form, or an elongated cylinder with hemispherical ends.*

A sphere 1 ft. in diameter holds 281.75 grains of atmospheric air, and approximately 21.67 grains of hydrogen, and the difference is 260 grains. That is to say, if an aërostat 1 ft. in diameter were to be filled with hydrogen gas, and the envelope and load together weighed 260 grains, equilibrium would be established, and it would not rise. But if the envelope and load be 100 grains, the buoyancy or flotation value would be equivalent to 160 grains. It is obvious that the efficient power of ascension, or the excess of the whole buoyant force over the absolute weight of the apparatus, would, by acting constantly, produce an accelerated motion if it were not checked, and eventually rendered uniform by the resistance or inertia of the atmosphere. If it were not for this resistance the velocity of ascent which an aërostat would gain would be in the same proportion as a falling body acquires in the same time as the efficient buoyancy is to the aggregate weight of the apparatus and the contained gas. We may estimate the final or uniform velocity from the following formula, in which D = diameter in feet, and P ascensional power or buoyancy in pounds, and V the ascensional velocity in feet per second, or that velocity which causes an air resistance equal to the buoyant force or flotation value. Then

$$V = \frac{40}{D} \times \sqrt{P}$$

* A "prolate spheroid" affords the maximum of buoyancy with the minimum of resistance to the air (see Prolate Spheroid Table in the Appendix), and may be defined as a solid proceeding from an ellipse.

and for example, take an aërostat 50 ft. in diameter with a force P of 576 lbs. Then the equation becomes

$$V = \frac{40}{50} \times \sqrt{576}, \text{ or}$$

$$\frac{4}{5} \times 24 = \frac{96}{5} = 19.2 \text{ ft. per second,}$$

or a mile in $4\frac{1}{2}$ minutes.

The final point to be considered is the stability of an aërostat at a certain altitude, at which the forces are in equilibrium.

For purposes of calculation we assume that the atmosphere is of the same density as at the earth's surface for 26,000 ft.—that is to say, homogeneous throughout—in order to find the altitude a to which an aërostat will rise until the volume of displaced air equals the capacity, and is as weight to weight.

The density at altitude a is $e\frac{-g}{k}a \times$ density at earth's surface (d), where e = the base of hyperbolic logarithms, and ka constant, g equivalent of gravity at earth's surface, 32.2.* Then if D = displacement of aërostat and adjuncts, and W = weight of aërostat, gas, and adjuncts,

$$W = Dg \times \text{density of air, and}$$

$$= Dg\varpi.e - \frac{g}{k}a.$$

After the altitude readings are corrected for temperature t and latitude λ, g may be corrected also, but since the error is trifling, as the radius of the earth is 4,000 miles,

* If the Brigg logarithmic system be used, the result must be $\times$ 2.3026, being the reciprocal of the modulus.

and a is necessarily less than B, it may be accounted negligible.

Taking an example, air being .08073 lb. per cubic foot, and hydrogen .005592 lb. per cubic foot, an aërostat 100,000 cub. ft. in capacity will weigh with the envelope, car, passengers, and accessories about 3,000 lbs., and the gas 559 lbs. = 3,559 lbs. The air displaced is 8,073 lbs. say, and the effective difference 4,514 lbs. Therefore the altitude a to which the aërostat must rise, at which the capacity weighs 3,559 lbs., is the normal altitude, at which the ascending force is neutralised, and vertical movement ceases. Then

$$a = e - \frac{a}{26000} = \frac{3559}{8073}$$

Therefore $a = \log. 8073 - \log. 3559 = 21{,}000$ ft. About half the original quantity of gas has probably escaped when this altitude has been attained, unless a suitable provision for storing it has been made. Therefore the weight 3,559 lbs. is reduced 280 lbs., and about 200 ft. is added to the altitude a. Nadar, in his large balloon "Le Géant," used a compensator, or a smaller balloon affixed to the neck of the larger balloon, and empty at starting, in order that the expanding gas may be conserved in the ascent. Green, in 1821, used a "guide, or trailing rope," which formed an automatic regulator, since when descending the aërostat was relieved of the weight, and this increased when ascending. This device is also useful as a fulcrum in dirigible aërostats, in which steering is imperfectly effected by sails or rudders.

Boyle's law regarding the expansion of gases is, "The density of a gas is proportional to its pressure for the same temperature."

The temperature at various altitudes is variable for

many reasons, such as meteorological changes and the like. The following formulæ are useful for obtaining data in respect of expansion of gas :—

Let P = pressure at 30 in. of mercury.
t = temperature of gas.
V = volume of gas at 30 in. of mercury.
v = volume of gas at any temperature t.
W = weight of gas at 30 in. of mercury.
w = weight of gas at any temperature t.
p = pressure at any temperature t.
k = co-efficient of expansion with each degree of temperature = .002036° Fahr., .003665° Cent.

(*a*) $p = \mathrm{P}(1 + kt)$.

(*b*) $v = \mathrm{V}(1 + kt)$.

(*c*) $\mathrm{V} = \dfrac{v}{1 + kt}$

(*d*) $w = \dfrac{\mathrm{W}}{1 + kt}$

(*e*) $\mathrm{W} = w(1 + kt)$.

Hydrogen gas varies with the method of manufacture, but when made by the decomposition of zinc by water and sulphuric acid, and the gas evolved is treated with quick or unslaked lime to eliminate the moisture, the lifting power is approximately 14.6 cub. ft. to 1 lb. in weight. And it may be assumed that 20 sq. ft. of varnished silk weighs 1 lb. In ascertaining the diameter and weight of an aërostat, let

W = total weight to be raised (aërostat included, with accessories).
w = weight of a cubic foot of air = .080728 lb.
w' = weight of the gas.
D = diameter of aërostat.

Then

$$D = \sqrt[3]{\frac{W}{.5236\,(w - w')}}$$

$$W = D^3\,(w - w') \times .5236.$$

We may, from the data afforded by the formulæ given, estimate the proportions of an aërostat to suit the conditions of various cases of adaptation, and may proceed to describe and analyse the different types that have been used for experimental or practical purposes.

CHAPTER III.

AËROSTATS.

IN dealing with the subject of aërostats it is not within the scope of this work to detail the older types of ordinary heated air and gas balloons, nor the record of aërial voyages already well known to the reading public, but rather to describe the various improvements of later date.

It is unlikely that the aërostat will in the future occupy any other position in aëronautics than that of a buoyant support for motive power and steering apparatus in combination with aëroplanes and aëromotors, except for military or surveying purposes, therefore we may enlarge upon it as an auxiliary appendage in the proper place.

The Serkis-bey aërial machine is a combination of an aërostat and a parachute, and when used in the latter capacity it may to some extent be steered.

The apparatus, as shown by the elevation, Fig. 7, consists of a light framework of radial rods *m*, with strengthening rods attached to a collar *e* upon the central hollow stalk which supports the structure. The convex surface inside *e* is lined or covered by an impervious membrane which forms the lower part of the umbrella-shaped aërostat *a*, *b*, *c*. The outer rim *b*, *c* forms the supporting hoop *g* for the car *j*. When it is desired to descend, the gas is allowed to escape by a valve at *a*, and the envelope when wholly or partially exhausted is

inversely compressed by the resistance of the air, and acts as a parachute. The cord or suspensory stay *l, d* is then tightened or released, and by thus changing the centre of gravity the envelope *a, b, c* is obliquely inclined, and the direction of descent may be guided or steered

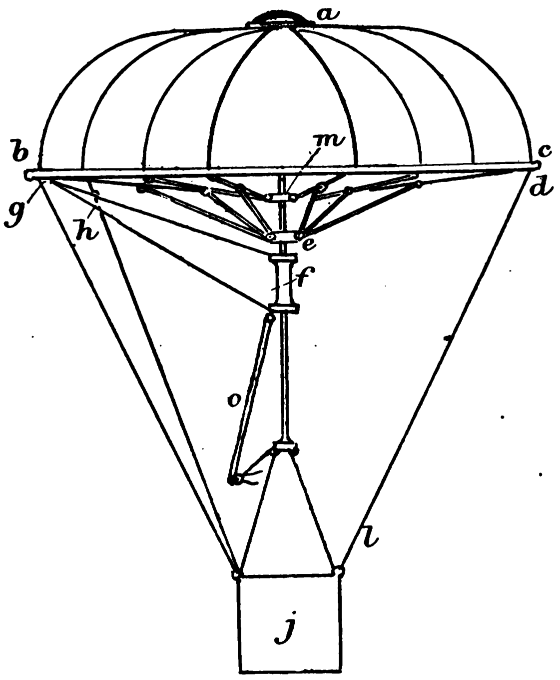

Fig. 7.

by a rudder *f, h* controlled by cords *o*. If the gas is not wholly exhausted, a fresh ascent may be made by throwing out ballast, and another oblique descent effected. This is noteworthy as an ingenious device rather than a practical machine.

The Gower aërostat is essentially a military machine, and is designed to automatically control the elevation, and also to release explosives at a predetermined time and place.

The principal feature consists in utilising the varia-

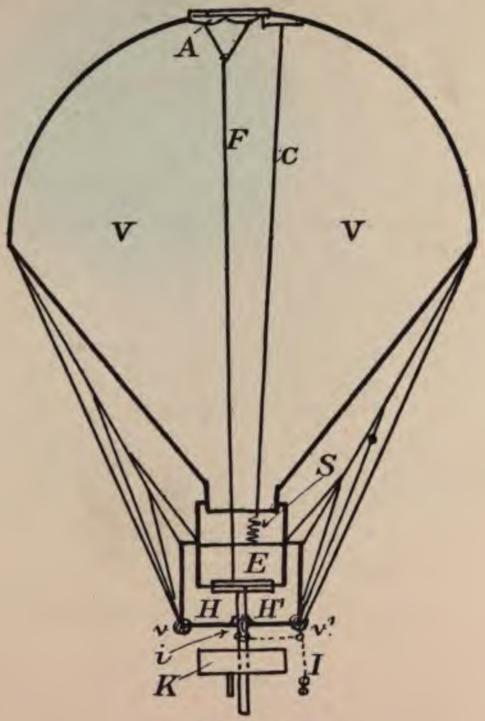

Fig. 8.

tion of the vertical length of the aërostat as it tends to rise or fall, to open the gas valve A, Fig. 8, or ballast valve E by cords C and F respectively, and in this manner to maintain automatically the desired altitude.

A spring S is interposed in order to preserve the tension of the cord C, and so to prevent the valve A from being operated until the shortening of the aërostat V exceeds a certain amount, which can be regulated by adjusting the length of C. The discharge of the explosive body or other freight K is effected by the release, by a time fuse I, of the latch *i*, thus allowing the rods H, H′ to

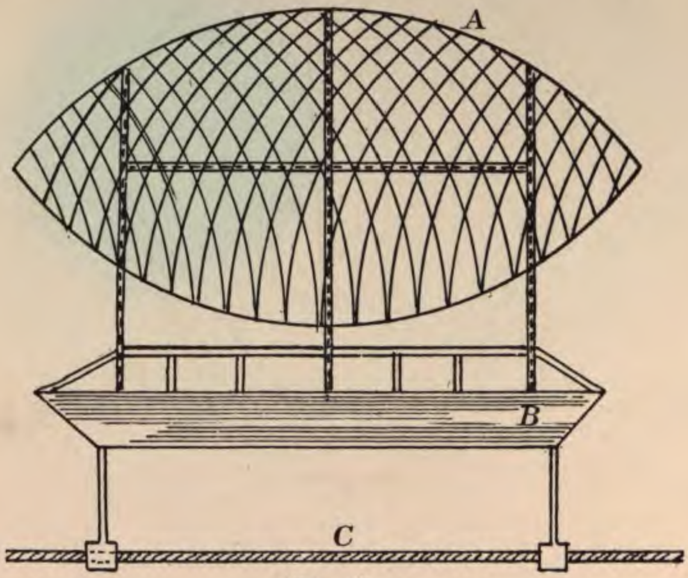

Fig. 9.

hinge upwards about *v*, *v′* and the suspending rings to slide off. Successive discharges may be effected by fuses of different lengths, or a number of cases may be arranged to be dispersed by the explosion of a small initial charge by the fuse.

The Bate aërostat is simply the adaptation of an aërostat to relieve the load carried by an endless rope

or chain transport way, and is shown by Fig. 9. The aërostat A supports a car B which is provided with grips for gripping the moving rope or chain C, and may cause the car B to move horizontally, and be stopped or

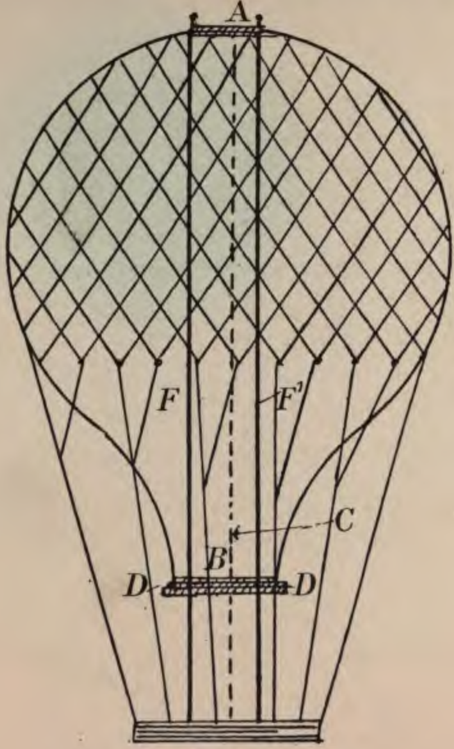

Fig. 10.

started by operating the grips. The function of the aërostat in this case is to relieve the rope C of the dead weight of the load.

The Dale aërostat is capable of conversion into a parachute, and is shown by the elevation, Fig. 10.

The aërostat is fitted with an upper valve A and a lower valve B, the valve A being covered on the inner side by wire netting, over which is stretched a strip of oiled silk or any other impermeable material. When it is desired to convert the aërostat into a parachute the strip is

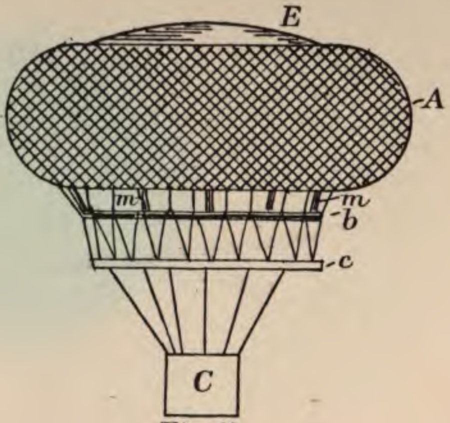

Fig. 11.

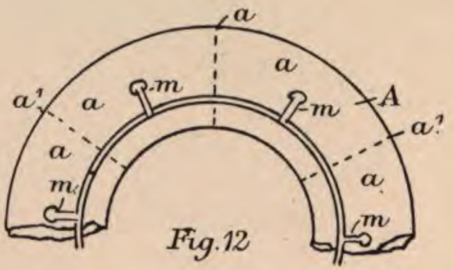

Fig. 12

withdrawn by pulling a cord C; the gas then escapes, and as the aërostat descends the lower half is forced into the upper half, B being guided by rollers at D, D′ along vertical guides F, F′. The lower valve B may be opened or closed to regulate the rapidity of the descent,

since the upper valve A is permanently open when the covering strip is withdrawn.

Sir W. A. Fryers has constructed an annular aërostat, shown by the elevation, Fig. 11, and the part plan, Fig. 12. The aërostat A is made in the form of an annulus, so that in the case of descending into the sea, the car C may

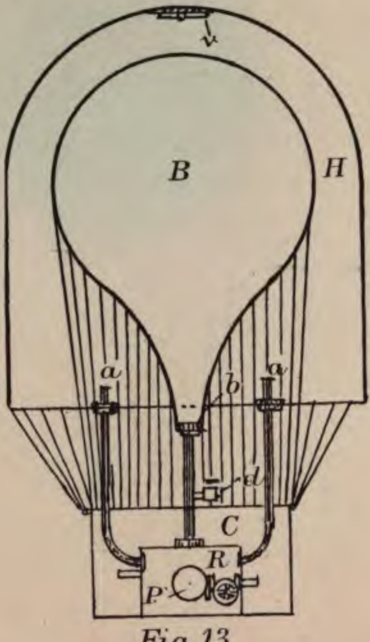

Fig. 13

float inside the annulus, which forms a protection against the sea. It is preferably divided by partitions a' into cells or compartments a, so that if one compartment is injured by shot in cases where the apparatus is used for military purposes, or similar accidents, the uninjured compartments may sustain the car. Each compartment

a is provided with a branch pipe and valve *m* terminating in a common pipe *b*. The car C is suspended from an insulating ring *c*, which is in turn supported by the netting covering the annular aërostat A. A piece of waterproof fabric E is stretched across the top to act as a parachute when descending. For reconnoitring in war-time a car is suspended from C by a long cable, so that the aërostat may float at a safe height.

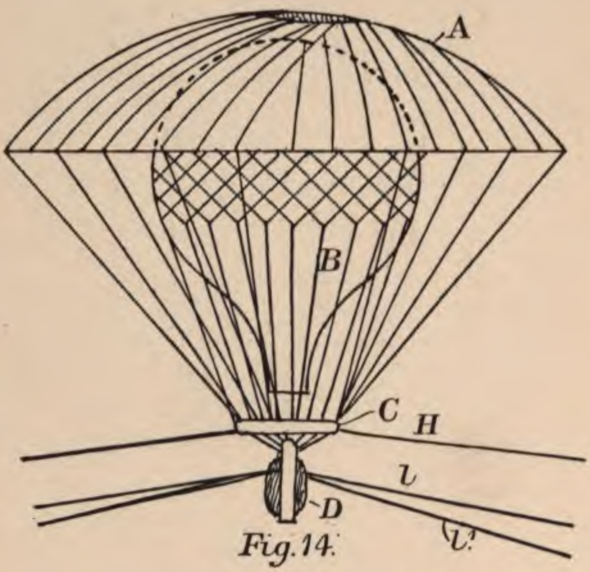

Fig. 14.

In Glendinning's aërostat, Fig. 13, the aërostat B is enclosed by a bag H, into which air is compressed, and supplied from a reservoir R in the car C through pipes *a*, *a*. The pressure is maintained by a pump P. Part of the reservoir R is divided so that the gas from the aërostat B may be stored, a safety valve *d* regulating the compression in order to protect the envelope, the neck *b* being closed;

a valve *v* at the top of the bag H enabling the air pressure to be regulated. The object of the device is broadly to effect regulation of the altitude by increasing or diminishing the surface pressure upon the outside of the envelope

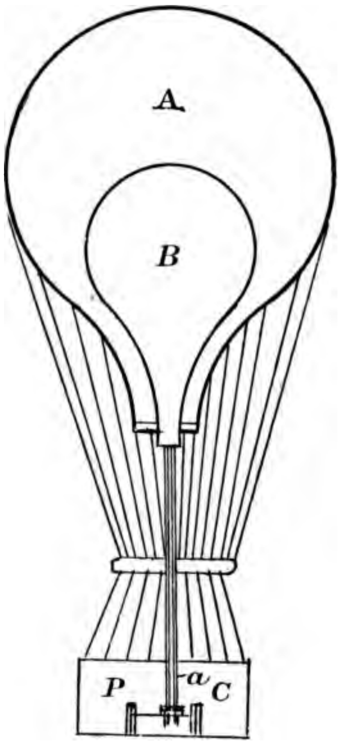

Fig. 15.

of the aërostat B. The inversion of the bag H may be utilised as a parachute in descending.

Tapscott's combined aërostat and parachute, shown by Fig. 14, is devised to support life-saving appliances

clear of the waves when rescuing shipwrecked persons by means of a cable and cradle or saddle. A parachute A is attached to the top of an aërostat B, and an insulating ring C is suspended from the outer circumference of A. The ring C carries the cable H, and a double sheave block D over which the life lines *l* and *l'* are rove.

Scott's aërostat (Fig. 15) is exactly the reverse of Glendinning's, before described, since air pressure is applied internally instead of externally. The outer envelope of the aërostat A is made of unusual strength, and an air bag B is fitted within it, which may be dilated or contracted by the manipulation of the pump P in the car C, and a suitable releasing valve, thus varying the buoyancy of the aërostat.

CHAPTER IV.

AËRODYNAMICS.

Air as a Medium.—Water is as a medium heavy and inelastic, and air is light and elastic. In propulsion water presents the maximum of recoil with the minimum of displacement, whilst in the case of air the conditions are exactly opposite. Therefore in constructing an aëromotor capable of practical work, the peculiar nature of the medium in which the apparatus has to float and to move by mechanical reaction calls for a structural form and adaption of motive power entirely different from that required upon sea or land. In marine propulsion, a part only of the ship is immersed in the water, and being lighter than the medium in which it floats, is enabled to use this denser element as a fulcrum from which by oars, paddle wheels, screws, or jets, to obtain the reaction necessary to move it against the resistance of the water beneath and the air above the water line. A submarine vessel, when totally submerged, presents the nearest analogy to the aëromotor in practice.

The absolutely perfect aëromotor, the air-ship of the future, must necessarily be heavier than the surrounding air. We have noted in dealing in a preliminary manner with flight in nature, that the organism of such birds, animals, and insects are comparatively light in structure relatively to their bulk, not as regards the wing area or surface opposed to the air resistance in sustaining the body at a certain altitude or propelling it at a certain

velocity. We can construct a framework of metal, and provide a prime motor, but within our closest limits we could not, weight for weight, and space for space, make an aëromotor upon the scale of the stag beetle (*Lucanus cervus*) with the same conservation of energy and mechanical action.

But it is essential that an aëromotor should have the weight much in excess of the air displaced by it when at rest. The inertia of the mass is indispensable to the control and regulation of such an apparatus, so that it may be steered and propelled in exactly the same manner and with the same facility as a floating ship in the sea.

Weight.—A simple aërostat cannot be rendered dirigible by rudders or sails, since it is entirely surrounded by the medium it floats in, and is subjected to every air current in such a manner as to drift with it. Therefore, as may be seen by a weight-area table appended, the true air-ship should be of considerable weight, should start from a position of rest upon the earth by means of its self-contained motive power, and this force should propel it in any direction independently of any air currents; and at the same time the structure must be of sufficient strength to withstand the onslaught of a possible hurricane. All this is within the range of modern mechanical genius and engineering enterprise, but the one fatal objection stands in the way, and subverts the true lines of construction. This is not a scientific obstacle, but it may rather be termed a prudential one, and may be summed up by the consideration of the fallibility of all machinery, and the absolute dependence upon continuous action to prevent a terrible catastrophe in case of failure. Therefore, so far as one can foresee, the aërostat will always be an accessory to the air-ship, unnecessary in the propulsion, and a decided

disadvantage in steering, but certainly a safeguard to some extent against the worst form of accidents. It is only requisite to allow the buoyancy of the aërostat to balance the weight of the apparatus, the ascension and propulsion depending upon the motive power.

Flight may be attained by heavy powerful animals with a comparatively small wing area, there being no established ratio between wing area and weight, but an unvarying relation between the weight and velocity of motion. The following table shows the approximate area in square feet per pound avoirdupois for different types of birds and insects :—

Name.	Wing Area, Square Feet per lb.
Gnat	40.8
Bee	5.5
Stag Beetle	5.0
Swallow	5.48
Condor	1.3
Albatross	1.28

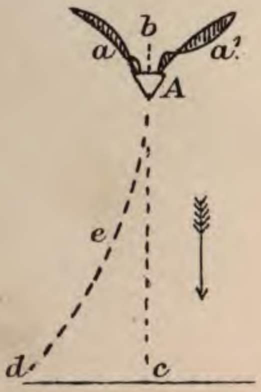

Fig. 16.

The little experiment illustrated by Fig. 16 shows the value of weight as a factor in propulsion. A cork A, pointed at the lower end, and having two feathers *a*, *a'* obliquely fixed in the flattened top, is let fall from a point *b*, and directly by the force of gravity should descend in the direction *b*, *c*. But the falling weight causes the oblique planes *a*, *a'* to displace the air, and by rotating against the resistance compels A to describe the trajectory *b*, *e*, *d*.

Thus the problem resolves into the relative values of weight, power, velocity, and small surface area *versus* buoyancy, small power, slow speed, and extensive sur-

face area. No rule can be laid down for establishing a basis for construction. Each form or type must be calculated according to the various conditions that are to be fulfilled.

Wing Movements.—Professor J. Bell Pettigrew, in his records of experimental research, gives a theory of wing motion which is borne out by practical experiments in producing artificial wing flight in exactly the same manner in which it is performed by nature; and Professor E. J. Marey has also by means of the sphygmograph produced graphic records of the actual natural movement. Professor Pettigrew does not agree with the

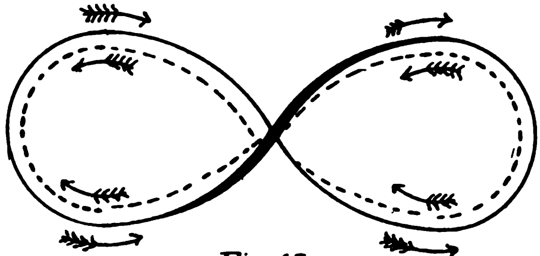

Fig. 17.

theories adduced to prove the dilation and contraction of the spiral nervures, but holds that the *radius* and *brachial* nervures are operated from the thoracic articulation as ball and socket, or universal joints having such a combined movement as to cause the margin and tip of the wing to describe a figure of 8. Thus the wings obtain leverage by presenting an oblique surface to the air, the obliquity increasing behind forward and backward during extension, when a sudden effective stroke is given, and decreasing oppositely during flexion or slow return stroke. Fig. 17 shows the figure of 8 described by the tip and margin of a wing in the motion

of flight. The continuous line shows the extension, and the dotted line the flexion. A second line midway between the extension full and flexion dotted line would indicate the movements of the tip, but it is not shown for purposes of clearness. In Fig. 18 we see this movement carried out in a wave-like direction as in horizontal flight. Here *a*, *b* represent the wave crests, and *c*, *d*, *e* up-strokes, and *f* is a point corresponding to the anterior margin of the wing (*radius*), forming the centre of the semi-rotary down-stroke *a*, *g*, and *g* is a point corresponding to the posterior margin (*brachials*), forming the centre for the semi-rotary up-stroke *d*, *f*. In Fig. 19 the diagram shows the mechanical action of the muscles, in order to spread the wing in extension and close it in flexion, the arrows showing the direction.

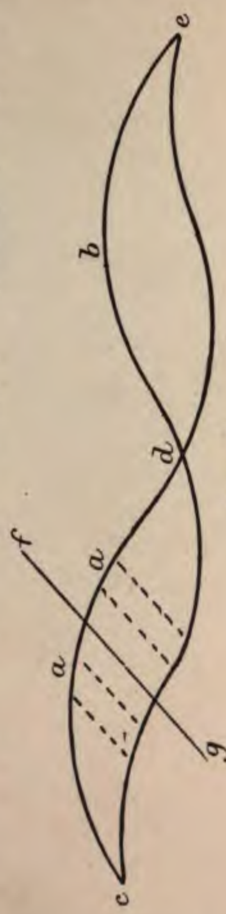

Fig. 18

The fact that the wing is both elastic and flexible is a necessary factor in considering its efficiency as a means for converting energy into useful work. The compound semi-rotary motion, aided by elasticity and flexibility, enables the wing in performing its functions to twist and untwist by partly vital and partly mechanical means, that is to say, partly by muscular

action and partly by the air resistance, the wing meets its own reverse current upon the return stroke which materially aids in the progressive flight.

If the wings were not disposed in such a manner as

Fig. 19.

to have a semi-rotary movement on two axes (*radius* and *brachial*) with an eccentric stroke, the structure would be so cumbrous as to be controlled by the air instead of controlling it.

When the wing descends the body is slightly elevated,

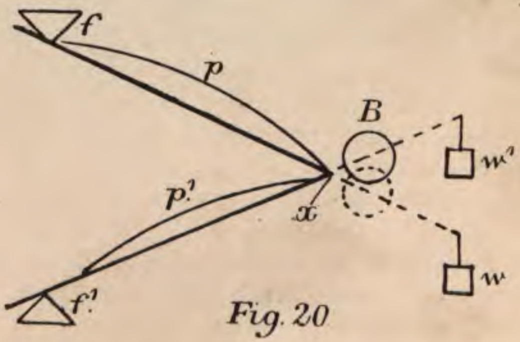

Fig. 20

that is, the wing comparatively is active and the body passive. The descending body causes the wings to elevate, the body being active and the wing passive. The muscular force of depression upon the reaction of the

compressed air reverses the order. Four wings are most suitable for artificial wing flight, two on each side of the apparatus, the driving mechanism causing two to be elevated whilst two are depressed.

Fig. 20 illustrates the action of the wing upon the air, f, f' being the movable fulcra, or air resistance, p, p' power applied to the wing surface, B the body, and x a universal joint, w, w' being weights upon extensions of p, p'. When the wing ascends at p the resistance f retards it, and forces B or w down slightly. The opposite resistance f', when p' is on the downward stroke, similarly raises B or w'.

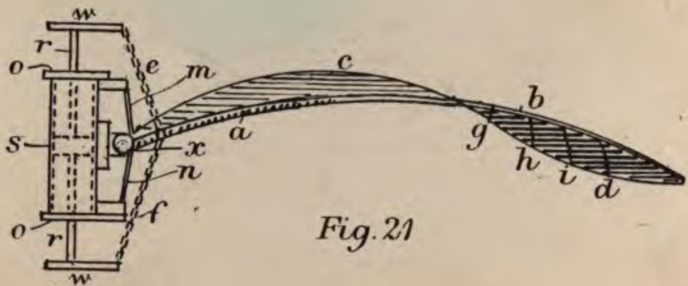

Fig. 21

We come now to the production of winged flight by mechanism, to imitate nature as far as possible, and for purposes of illustration have chosen experimental subjects, some of which are capable of development for practical purposes, although hitherto made upon a small scale for laboratory experiments. Pettigrew's piston wing (Fig. 21) is an example worthy of notice, although its motion is confined to a single axis.

A curved wing c, b is supported by the radius a in a universal joint, and connected by chains e, f to the upper and lower crossheads of a piston rod r, r attached to a piston s within a cylinder o, o, two elastic bands m, n

being added, and placed so as to support the wing in its normal horizontal position when at rest. Air or gas under pressure is admitted by suitable valves alternately to the top and bottom sides of the piston *s*, and the reciprocatory movement thereof causes the wing to be correspondingly raised and depressed. The wing surface is strengthened by transverse bars *g*, *h*, *i*, *d* between the radius and the posterior horizontal member. Another movement adapted to the use of four wings is that employed by Walker in his experiments. The wings are operated from universal or ball and socket joints *w*, *w'*,

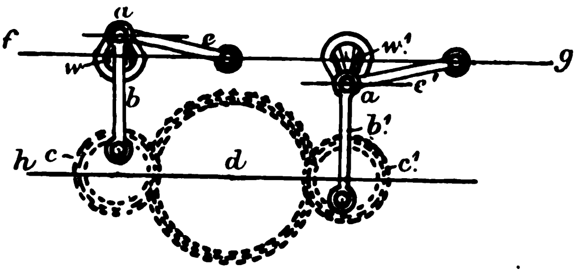

Fig. 22

shown by Fig. 22, these joints having their centres in one plane *f*, *g*, and a cranked extension *a*, *a'* upon the rolling part of the joint. Each crank *a*, *a'* is oppositely situated relatively to the other. Two pinions *c*, *c'* are driven by a central spur wheel *d*, the axes being upon the line *h*, *i*. Crank pins upon the pinions *c*, *c'* drive the joints *w*, *w'* by means of connecting rods *b*, *b'*. Thus, although the crank pins complete a whole revolution, the joints *w*, *w'* make a semi-rotation only, the dip being from forwards to backwards. This is effected by means of short links on the line *f*, *g* jointed to the crank pins *a*, *a'* at one end and to the framework at the other. Thus

the displacement of air and consequent reaction tends to give a forward and upward movement to the apparatus, and the posterior pair of wings, by reason of the opposite movement imparted to them, continue the action of the first pair. A modification* of this arrangement provides for a rapid down and back stroke, and slow upward and forward strokes. The spur wheel *d* is made with two diameters, and each of the pinions *c*, *c′* similarly shaped. The larger diameter of *d* engages with the smaller diameter of *c* when that wheel is effecting the quick down-stroke, and the smaller diameter of *d* is simultaneously driving the larger diameter of *c′* whilst it is performing the slow up-stroke of the posterior wing. The arrangement is analogous to the quick return motion of an ordinary shaping machine.

In Smythie's system he employs a carriage mounted upon wheels, the wings being flapped by a steam or any reciprocating motor. The resistance of the air to the up-stroke is reduced by making the wings of several overlapping parts, and giving the shafts liberty to turn in their sockets through an angle of about 35°. Each wing may be made of a silken or linen web stretched between the tapering steel shaft corresponding to the radius, and a cord attached to a point just below the pin *a*, Fig. 23, the shaft being held by a pin in a tubular socket E. The cranked double lever D has within it a circular eccentric sheave with an eccentric strap carrying the end of the link F, and centred at *d*. The ascent of the piston rod B pulls up the lower end of D by the links *l*, *l*

---

* The last described differential gearing was used by me to operate valvular flapping planes of large area. The automatic valvular surface was found to be a failure, even at low velocities, the undulation of the displaced volume of air in no way conforming to the disposition and arrangement of the valves.

jointed to the crosshead *c*, the link F pulling down the tube E with a very oblique action. The shaft of the wing thus turns through an angle of 35° by the action of the air. During the descent of the piston in the cylinder C the pin *a* presses the tube E and link F upwards. A flat sail is used as a steering tail.

The apparatus made by Cornelius (Fig. 24) is designed to embody the mechanical principles brought into exercise in the flight of a bird, and consists in the combination of

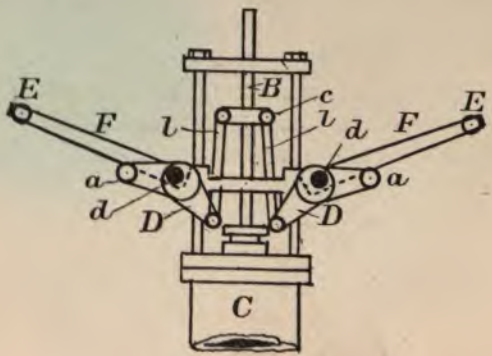

Fig. 23.

a body capable of supporting the aëronaut with wings and tail of special construction. It is intended to utilise the atmospheric pressure by "giving to the machine a larger underneath or supporting surface than the upper surface, and the reacting motion of the atmosphere against the action of the wings; the principal feature in realising the latter effect being that such reaction shall take the same direction as that in which the flying body is to move." In flying, the wings and tail present concave surfaces backwards and downwards. The body *l*

is strapped to the aëronaut's back, and may be provided with a saddle *a*. The wings *r*, *r*, having ball and socket joints *e*, *e*, and handles *f*, *f*, are worked by the arms, and the part *q'* of the tail *q* is spring-jointed at *g*, and controlled by a cord and lever worked by the feet. Cords *t*, *t'* from a flat spring *h* bent overhead assist the forward strokes of the wings *r*, *r*, and the elastic cords or springs *s* impart a kind of feathering motion. A similar apparatus

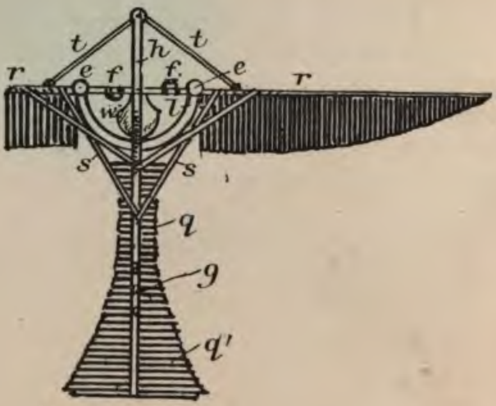

Fig. 24.

may be provided with a motor, and attached to a car and aërostat.

It is not a practical idea to construct a machine to carry a man, and to depend upon his unaided efforts to produce the required velocity of motion and power; apart from the fact that continuous exertion is impossible owing to the muscular structure not being adapted to the requirements of sustained flight, we must consider the actual work done. Let a man weigh say 150 lbs.,

and a specially light machine 10 lbs., and the comparatively low rate of velocity be 60 ft. per minute, then

$$150 + 10 \times 60 = 9{,}600 \text{ foot pounds}$$

and the average work of a man is

$$\frac{33000}{8} = 4{,}125 \text{ foot pounds,}$$

which is less than half that which is needed. In this instance the value of the wings as aëroplanes must be depreciated, since the sensitive anticipatory function incidental to equipoise, such as obtains with birds and other flying animals, is non-existent in man. For instance, if a perfect mechanical model of a man was made in perfect proportion, and the walking movement exactly imitated, the body could not for a moment be supported upon the area of the soles of the feet. Yet in nature a man may immediately stand upon one leg, and cannot lucidly define the alteration of the equipoise nor the stages of its progress. That is because it is anticipatory, and man has it in walking perfectly, and a bird in flying, but the same sense is imperfect in the bird when walking, as in the man when attempting to fly. Therefore the basis of the apparatus for artificial flight is not to render a man capable of flying, but to construct a machine that will fly and carry a man who may control it without the necessity for an anticipatory or ultra-sensitive function of equilibrium. We do not for this reason enlarge upon this type of machine, although many have been invented and tried experimentally with indifferent success, some being adapted to cycles and wheeled frames.

In Quartermain's apparatus the wings are actuated by an ordinary steam engine in which the steam is mixed with the products of combustion. These wings are

balanced by springs and arranged to flap together, and are mounted on rocking shafts which are on a swivel piece, and swivel joints are introduced in the connections to the cranks, so that the plane of flapping can be altered, a special arrangement being provided for altering the front pair independently of the others for steering purposes. The wings are curved transversely, and a flexible blade runs along the posterior margin of each. They

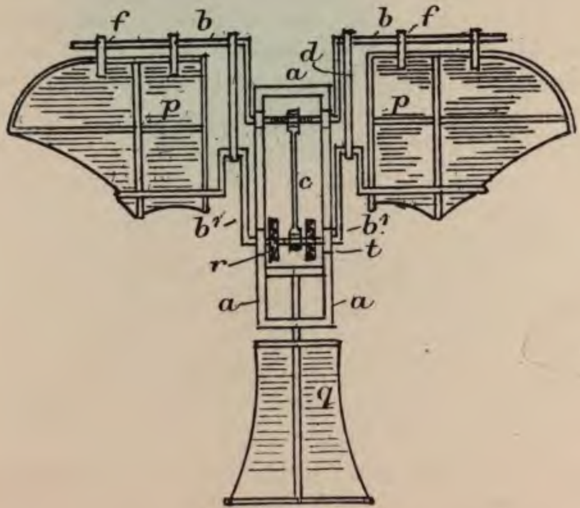

Fig.25

are arranged to swivel through a regulated distance about a longitudinal axis, which is nearer the anterior than the posterior margin, by which arrangement useful effect may be derived from both up and down strokes.

Capone's machine is shown in plan by the diagram, Fig. 25, in which the wings *p*, *p* are actuated by crank arms *b*, *b′* working in a frame *a*, and connected by rods *c*, *d*. They are freely suspended from the arms *b*, *b* by means

of rings *f*, but are independent of the arms *b'*, which serve merely to regulate their inclination. The rear part of each wing is preferably hinged to the main part, and works against stops, so that at the commencement of the upward movement it has a greater inclination to the horizon than the wing itself. The frame *a* is provided with a steering tail *q*, and the mechanism is driven from any suitable light motor by the wheels *r*, *t*.

Upon reference to Chapter I., dealing with the membranous wings of insects, we have noted that the longitudinal nervures each contain an inner spiral trachea, and that a theory of vibratory flight due to the dilation and contraction of these trachea has been propounded.

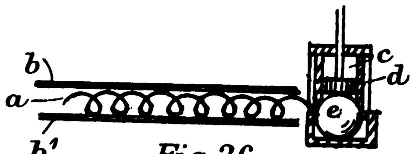

Fig. 26.

M. Victor Galliene has experimented in this direction, as shown by the sectional view, Fig. 26, in which *a* is a spiral elastic tube representing a trachea, and terminating in an elastic ball or air reservoir *e*. This is rapidly expanded and contracted by the vibration of a piston *d* within a cylinder *c*. Two elastic membranes *b*, *b'* are stitched or sewn together in seams, so as to enclose the several trachea extending radially from the root of the wing, and operated alternately in pairs. Finely tempered steel wires of tapering form are used to impart the necessary rigidity to the structure. In the experiment there were eight cylinders, each operating the corresponding artificial nervure on opposite wings, four nervures to the anterior wings and four to the posterior.

The weight of the model was 9.42 oz., and an inflated aërostat attached to the frame had a buoyancy equal to 8 oz., leaving 1.42 oz. to be raised by the wings; a small electro-motor with a rocking shaft or beam operating the pistons with the requisite progressive alternations. The power was derived from eight accumulator cells, not carried, but connected by flexible wires. The entire wing surface was 1.94 sq. ft., and the piston strokes 480 per minute. The result was to raise the machine 18 in.

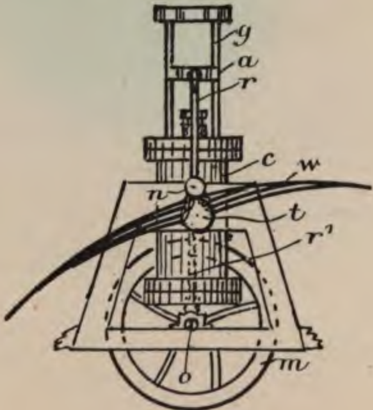

Fig. 27.

from the bench, where it floated indefinitely with no progressive motion due to the mechanical effect, but very sensitive to air currents. When screened so as to be free from the effect of these currents, the movement was gyratory around an eccentric axis, which was probably due to unequal balancing. The addition of two more accumulator cells in series had no further effect than to increase the velocity of gyration. Without condemning the theory as absolutely untenable upon

the result of this experiment, it does not appear feasible that the trachea are intended to produce the movement necessary for flight, but rather that they stiffen the wing at certain periods during its stroke in order to utilise the reaction of the air displaced.

Middleton's wing motion is shown by Fig. 27, in which an oscillating cylinder *c* is mounted upon trunnions at *t*, the piston rod carrying a crosshead *a* within guides *g*. A connecting rod *r* couples the crosshead *a* with a

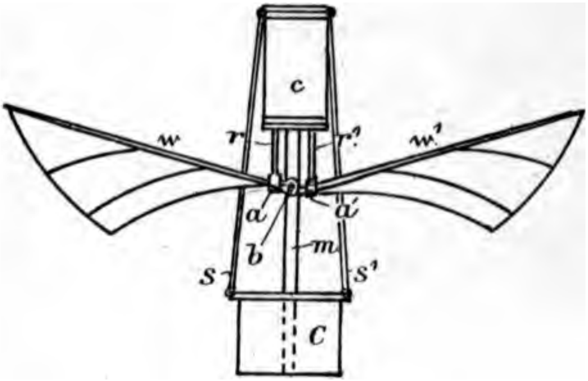

Fig. 28.

crank pin *n* upon a universal joint carrying the wing *w*, this joint being attached by its bearings to the trunnion *t*, so that it may oscillate with the cylinder *c*. A second connecting rod *r'* operates a crank shaft *o* at the base of the frame, upon which is fitted a flywheel *m* to secure uniformity of motion, and also to maintain the oscillation of *c*, which, in addition to the flapping movement due to the rod *r* and pin *n*, is necessary to produce the angular progressive action.

In Marshall's apparatus (Fig. 28) a cylinder *c* is

mounted upon a car C by a hollow rigid mast *m* and stays *s*, *s'*. The wings *w*, *w'* are jointed to the mast at *b*, and connected at *a*, *a'* to two piston rods *r*, *r'*, which are

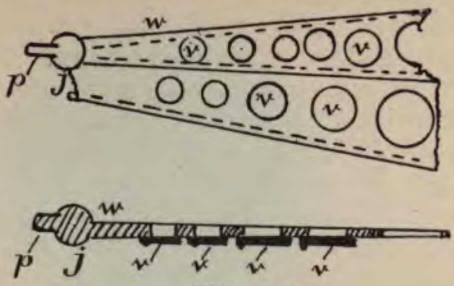

Fig. 29.

both attached to the same piston head. Upper and lower wings may be used, in which case the mast is

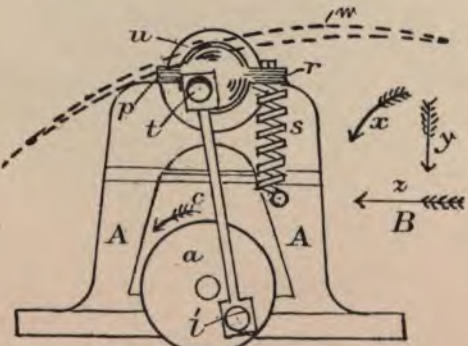

Fig. 30.

carried beyond the cylinder, and two pistons are employed. Steering is effected by a pivoted vertical plane.

In many cases valves or louvres are employed to lessen the resistance during the upward stroke, and an

example of this arrangement is shown by Fig. 29, in which the wing *w* is mounted upon a ball joint *j* with a crank pin *p*, and the surface is pierced for valves *v* hinged or freely suspended on the under surface so as to be closed by the air pressure on the down-stroke, as shown by the section. In actual practice these valves are useless.

A wing motion is shown by Fig. 30, in which a crank disc *a* is rotated by a suitable motor, and connected by a connecting rod to the crank pins *t*, *t'*, the pin *t* operating the ball joint *u* carried by the frame A, and forming the root of the wing *w*. The first movement of *u* is rotary until the pin *p* is stopped by the stop on A, when the continuation of the motion is downward, as shown by *y* in the diagram B, the first movement being according to *x*, and the result of the whole as *z*. A spiral spring *s* attached to a prolongation *r* upon *u* reverses this motion on the return or upward stroke.

So far we have dealt with artificial wing propulsion briefly as according to known experiments, but in treating of aëromotors or air-ships these and other motions will be detailed, since the aërostat, aëroplane, wing and screw propeller are frequently employed one with the other, or all in combination.

CHAPTER V.

SCREW PROPULSION, PADDLES, AND AËROPLANES.

IN dealing with the problem of the best mode of applying motive power to overcome air resistance, we have to consider that the displacement and reaction of a volume of air at a given velocity is essential in the first instance, and secondly the added resistance of the wind when it is opposite to the plane of motion, or as an aid to such motion when it has the same direction.

Air Resistance.—In calculating the resistance of the air as a pressure against a plane surface moved through it at a given velocity, we may deduce from experiment that the air resistance varies as the square of the velocity nearly, and to an inclined surface as the 1.84 power of the sine × cosine. The conformation of a plane surface makes no appreciable difference in the resistance, but the convex surface of a hemisphere with a surface area double that of the base has only half the resistance, hence the approximation of the true shape of the ends of elongated aërostats, or, what is still better, the employment of prolate spheroids.*

* The resistance tables are based upon Smeaton's definition of Rouse's experiments, viz., an air current with a velocity of 88 ft. per minute exerts a pressure of .005 lbs. per square foot on a flat surface. Dr Hutton shows that the resistance of a sphere is $\frac{1}{2.4}$, that of a disc having the same diameter. Sir George Cayley found the resistance to a prolate spheroid, whose major axis was three times the length of the minor axis, to be $\frac{1}{4.8}$ that of a circular plate, the diameter of which is equal to the minor axis.

Let P = pressure against plane a area in square feet, and v velocity in feet per second.

Then $P = .002288\ av^2$ = pounds per square foot.

Power.—Having determined this factor, the following table will give the relative velocities and power:—

Velocity.		Power.
Miles per Hour.	Feet per Minute.	Horse Power per Square Foot.
10	880	0.013
15	1,320	0.044
20	1,760	0.105
25	2,200	0.205
30	2,640	0.345
50	4,400	1.64
75	6,600	5.54
100	8,800	13.13
150	13,200	44.29
200	17,600	105.00

Calculated from $HP = .00000000001926\ av^2$, varying nearly as the square.

Wind Resistance.—When air passes as a wind current into air of less density, the velocity of its passage is measured by the difference of the densities of the air in both cases.

Let D = the maximum density, and d the minimum density in inches of mercury; and t the temperature in degrees Fahrenheit at the time of passage, and V the velocity in feet per second.

$$\text{Then } V = 1347.4\sqrt{\frac{D-d}{d}}\,(1+0.002088\ t).$$

And to calculate I = direct impulse in pounds per square foot.

$I = V^2 \times .006667$ where V is knots per hour.

$I = V^2 \times .005016$ where V is statute miles per hour.

TABLE OF VALUES OF I.

V. Miles per Hour.	I.	V. Knots per Hour.	I.	V. Miles per Hour.	I.	V. Knots per Hour.	I.
1	.0050	1	.0067	24	2.89	24	3.84
2	.020	2	.027	26	3.39	26	4.51
3	.045	3	.060	28	3.93	28	5.23
4	.080	4	.107	30	4.51	30	6.00
5	.125	5	.167	32	5.14	32	6.83
6	.181	6	.240	34	5.80	34	7.71
7	.246	7	.327	36	6.50	36	8.64
8	.321	8	.427	38	7.24	38	9.63
9	.406	9	.540	40	8.02	40	10.7
10	.502	10	.667	45	10.2	45	13.5
11	.607	11	.807	50	12.5	50	16.7
12	.722	12	.960	55	15.9	55	20.2
13	.848	13	1.13	60	18.1	60	24.0
14	.983	14	1.31	65	21.8	65	29.3
15	1.13	15	1.50	70	24.6	70	32.7
16	1.28	16	1.71	75	26.9	75	37.6
17	1.45	17	1.93	80	32.1	80	42.7
18	1.63	18	2.16	85	36.4	85	48.59
19	1.81	19	2.41	90	40.6	90	54.0
20	2.00	20	2.67	95	44.9	95	58.78
21	2.21	21	2.88	100	50.2	100	66.7
22	2.43	22	3.23				

The relative kind of wind accompanying these velocities and pressures :—

	Miles per Hour.	Pounds per Foot.
Hardly perceptible - -	From 1 to 2	From .005 to .006
Just perceptible - -	,, 2 to 3	,, .02 to .04
Light wind - - -	,, 4 to 5	,, .08 to .125
Light breeze - - -	,, 6 to 7	,, .181 to .246
Moderate breeze - -	,, 8 to 9	,, .321 to .406
Fresh breeze - - -	,, 9 to 1[illegible]	,, .406 to .983
Strong breeze - - -	,, 15 to 20	,, 1.13 to 2.00
Moderate gale - -	,, 22 to 24	,, 2.43 to 2.89
Fresh gale - - -	,, 26 to 30	,, 3.39 to 4.51
Strong gale - - -	,, 32 to 36	,, 5.14 to 6.50
Heavy gale - - -	,, 38 to 40	,, 7.34 to 8.02
Storm - - - -	,, 45 to 50	,, 10.2 to 12.5
Great storm - - -	,, 60 to 70	,, 18.1 to 24.6
Hurricane - - -	,, 80 to 100	,, 32.1 to 50.2

From the above data the details may be deduced by calculation respecting the area, angles or pitch, and velocity of screw propellers, paddles, jets, and the lifting power of aëroplanes when propelled under varying conditions of the air currents. It is obvious that the structure of an air-ship or aëromotor must be of sufficient strength to withstand the onslaught of a storm, which may suddenly arise before the ordinary precautions can be taken, the premonitory signs not being apparent at considerable altitudes in the same manner that obtains at or near the sea level. For instance, when the earth is obscured a fall in the barometer may mean an increased altitude, since under these conditions the rapid changes of the instrument render it comparatively useless as a weather guide.

Screw Propellers.—The action of a screw propeller as a means of moving a body through air is analogous to that of a similar propeller totally immersed in water, allowing however for the different degrees of density between the two media, and more especially that air is an elastic medium, and water is comparatively non-elastic.

The work done in propulsion is due to the reaction of a volume of air projected backwards, which must be equal to the air resistance at the given velocity of propulsion. There occurs a negative quantity termed slip, which is approximately $S = P - d$ where P = length of pitch, and d = distance advanced in one revolution, then S = slip in feet or other terms of measurement of P and d.

Unless the volume of air displaced be of infinite quantity, the slip is a necessary factor.

In calculating the proportions of a screw propeller, before type and form are considered, the first problem is: What is the best proportion between these and the volume of air displaced? Or in other words, the proper ratio of diameter and pitch, with a constant or varying velocity. It may be borne in mind that the weight of a prime motor generally varies inversely as the speed in revolutions per minute, and the energy of reaction of displaced air r varies as $r \times V^2$. Thus the propeller area which will propel an air-ship with a given slip ratio is directly as the air resistance and inversely as the square of the speed, and at such moderate speeds as are attainable, the same propeller area will overcome a given air resistance with a given slip ratio, and areas varying directly as the squares of the resistances. At high velocities the slip ratio increases with the given propeller area.

The maximum of efficiency is not obtained by extending the area of the propelling plane to minimise

the slip, but the slip angle that gives the maximum. The value of θ ($=\sqrt{.00047}$) which gives the maximum efficiency is the same whatever be the actual pitch angle.

The speed rule is (exclusive of slip)—

V = velocity in miles per hour.
P = pitch of propeller in feet.
R = revolutions per minute.

$$\text{Then } R = \frac{88\ V}{P}$$

$$P = \frac{88\ V}{R}$$

$$V = \frac{PR}{88}$$

The pitch of screws varies as the ratio of the area of the disc or circle described by the tips to the area of the air-ship affording resistance to the air through which it passes, *i.e.*, the maximum sectional area.*

IN THE CASE OF TWO BLADES.

Ratio of disc to section is 1 to	6.0	5.0	4.5	4.0	3.5	3.0	2.5
Ratio of pitch to diameter of disc is 1 to	0.8	1.02	1.11	1.2	1.27	1.31	1.4

AND IF FOUR BLADES ARE USED.

Ratio of pitch to diameter of disc is 1 to	1.08	1.37	1.49	1.62	1.71	1.76	1.89

The area depends upon (*a*) the shape or type of propeller; (*b*) the situation of it in the air-ship or aëromotor;

* Haussmann gives as the best proportions for air screw propellers, the angle to be from 18° to 23° pitch = diameter × 1.333, the latter being for three blades, which he considers to be a preferable arrangement to one or two blades of large area, or four blades of less area. This prevents the double displacement of the volume of air, and the consequent loss of power by subjecting the surface area to air in which the density is increased by displacement, and to which the maximum velocity is already imparted.

(*c*) whether it is shrouded or not; and (*d*) how many propellers are used.

Fig. 31 shows in the side elevation A and end elevation

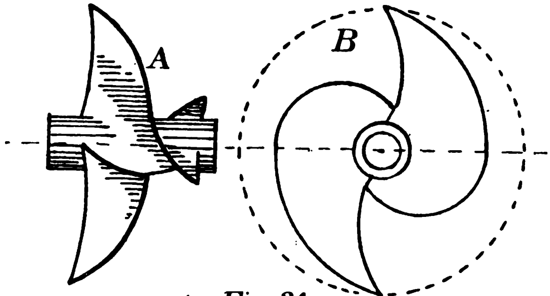

Fig. 31.

B the evolution of Rennie's screw propeller from Erichsen's original adaptation of a double helix (Fig. 32). Rennie

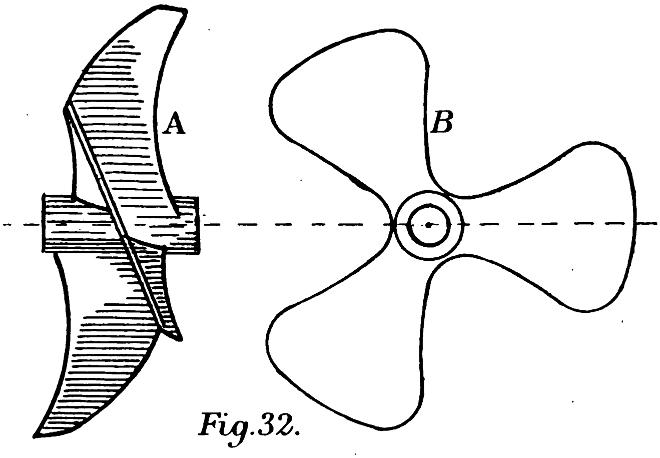

Fig. 32.

adopted an inverted cone as a basis of construction and modifications of these types.

Sir George Cayley made many experiments in the

application of an elastic screw propeller for aërial propulsion, but did not go beyond laboratory practice.

In Fig. 33 is shown one of his aëromotors, which, although a toy, serves to mark a distinct advance in the progress of this branch of science. Two corks *c*, *c'* are connected by light cane rods *a*, *a'*, and a wire hook *e'* is rigidly attached to *c'*. A similar wire hook *e* passes freely through *c*, and is fixed to a cork *d* carrying two vanes or feathers *w*, *w'* forming the blades of the propeller. An elastic band *b* is stretched between the hooks

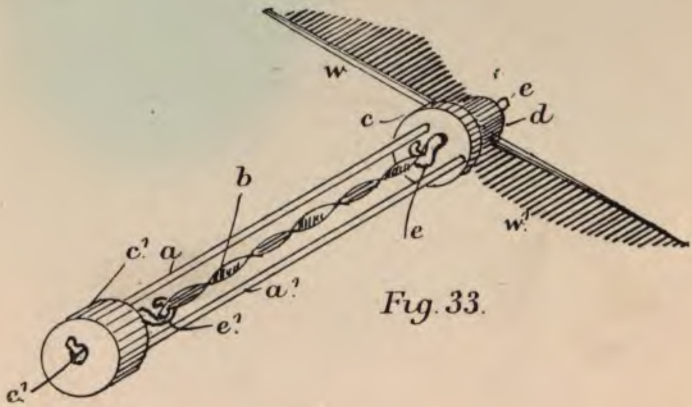

Fig. 33.

e, *e'*, which may be wound up by twisting the propeller on *d* in the opposite direction to which it is to travel. When released, the tension of *b* causes the propeller to revolve rapidly in the right direction, resulting in a short aërial flight of the apparatus. Cayley further duplicated this arrangement by adding a reverse propeller to the hook *e'*.

Various types of elastic propellers have been constructed upon the lines of Erichsen or Rennie, such as that shown by Fig. 34, in which the blade is built up of

thin metal sheets or laminæ *a* superimposed upon each, and slotted to freely receive a stud *b* attached to the

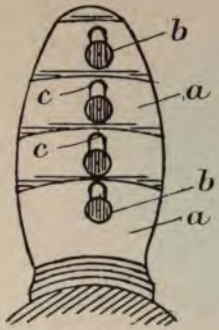

Fig. 34.

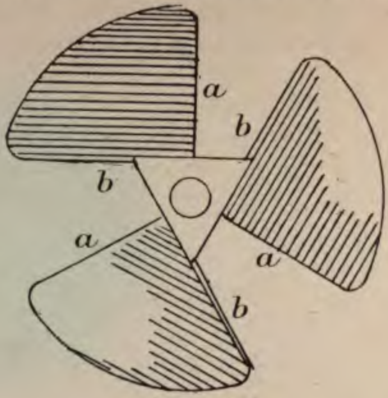

Fig. 35.

preceding plate, in a similar manner to the building up of a coach spring.

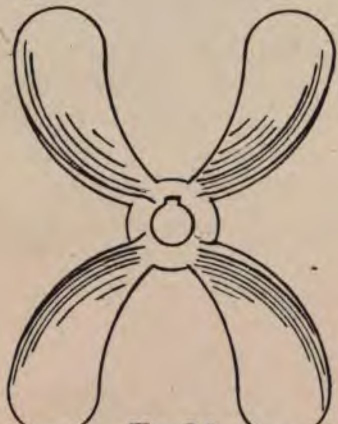

Fig. 36.

Henderson's propeller (Fig. 35) has a triangular boss, and the blades *a* are tangential to the boss at their lines

of attachment *b*. The sections of each blade *a* parallel to the edges follow regular parabolic or hypobolic curves, and the lines or edges *b* are in planes parallel to the axis, and the other edges are perpendicular thereto.

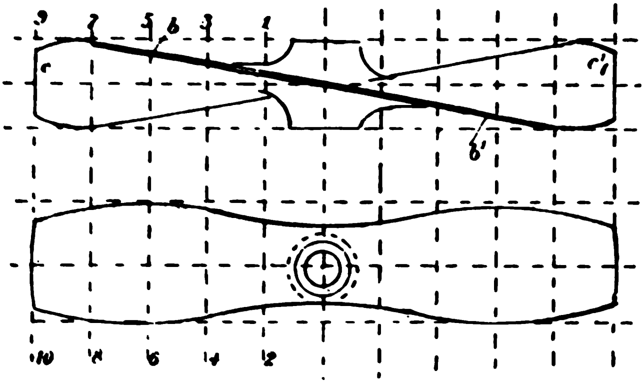

Fig 37.

In Fig. 36 is shown Vogelsand's propeller, in which the blades are arranged equidistantly around the boss, or in pairs, each being similar to the one diametrically

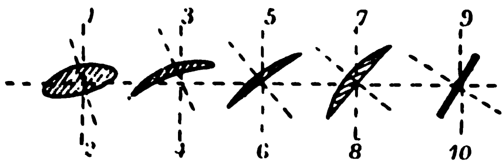

Fig 38

opposite, but has its leading and trailing edges reversed in direction to, but similar in curvature to, the trailing and leading edges of that on either side. They are alternately bent back and forward in the plane of rota-

tion, so that the water is thrown away from and towards the hub alternately. In the example shown, the blades may be made integral with the boss, but the design is equally applicable if they are bolted on. One edge of each blade may be straight, or partly straight and partly curved, and the other in the form of an ogee; and the pitch may be uniform or variable throughout the blade. The tips may lie in different planes, but the roots must lie in approximately the same plane.

Boisset and Mercier's screw propeller is shown by the elevations, Fig. 37, and the corresponding cross sections, Fig. 38. The efficient maximum width is estimated at one-fifth diameter at a point three-fifths of its length from the boss. The pitch is six times the

Fig. 39.

diameter, and the maximum inclination of the blade at the tip about 64°. The edges of the blades from *b* to *b′* are straight, and project beyond the boss, and the edges from *b* to *c* and from *b′* to *c′* are curved, while the tips are straight. Near the boss the propeller is convex, and becomes concave about the middle of the length, and straight near the tip, while the angle it makes with the axis increases from the boss outwards. This form of propeller in its revolution drives the displaced air toward a point in the axis about twice its diameter to the rear. It is preferable in practice to obtain the highest efficiency by using two propellers of opposite hand, arranged tandem-wise.

Fig. 39 illustrates Williams' propeller, in which the

distinguishing feature is that the blades are so constructed that the pitch increases uniformly from the periphery to the axis, where it is infinite.

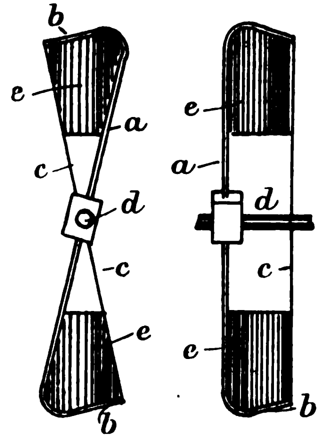

Fig. 40.

Alexander's flexible propeller is shown by the side and end views, Fig. 40. A tubular **Z** frame *ab* is

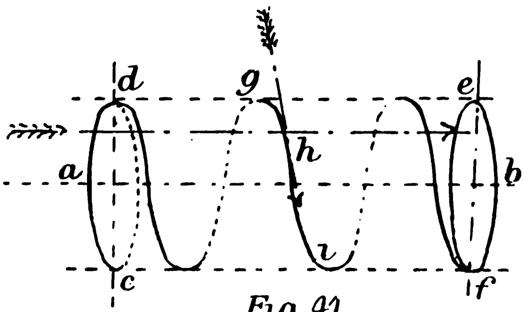

Fig. 41.

mounted upon an axis *d*, the ends being connected by a strong but light wire stay *c*, the blades *e* being attached to *abc*, and made of thin elastic sheet metal, or of fabric,

and suitably curved. The device is not a true propeller, since it cannot be properly pitched, but as a light elastic impulse appliance in air it has some merit.

According to Féraud, the proper method of construction of propellers for air displacement is to set out a series of concentric cylinders as shown by Fig. 41. The concentric cylinders *cd*, *ef* have a common axis *ab*, which is also the centre line of the propeller shaft. Upon each cylinder is described a helix *ghi* of given inclination, *gd* being the pitch equivalent of the periphery. The surfaces between this and the axis are filled in to correspond to the curves set forth by the helices.

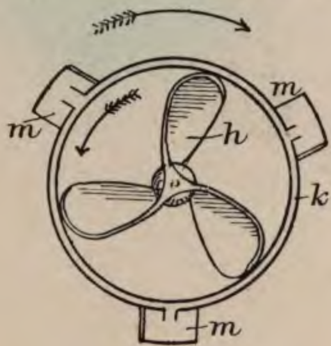

Fig.42.

Schmidt uses a shrouding which has inverse blades and may revolve oppositely to the propeller proper, or may be stationary. This is shown by the end view, Fig. 42. The ordinary screw propeller *h* revolves in the direction of the arrow, and is enclosed by a ring *k* with vanes or blades *m* inclined in a contrary direction to those upon the propeller *h*. The ring *k* and propeller *h* are revolved in opposite directions at the same angular velocity, and the object of using *k* is to utilise the energy of the displacement of air caused by *h*.

In Fig. 43 a propeller blade with "gliding lips" is shown, the invention of Mr W. Child. These lips are formed upon the leading and trailing edges of the blade as indicated by the dotted outline on the end elevation and cross sections in the figure. The circumference of the boss at its greatest diameter is equal to the pitch of the screw, and the contour is such that upon cutting it by a series of equidistant planes perpendicular to the

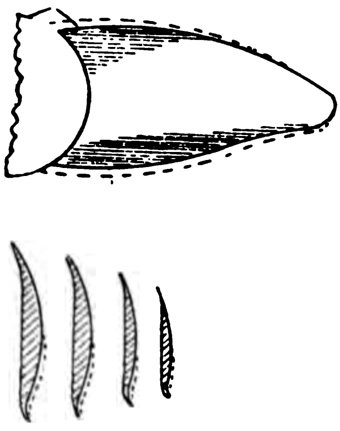

Fig. 43.

axis the enclosed area diminishes as the rear end of the boss is approached, on account of its increased size. This form of propeller is particularly adapted to enclosing rings or casing, both fixed and movable.

Another instance illustrating enclosed propellers is that of Storz, shown by Fig. 44. The propeller boss *a* is comparatively massive, and of considerable diameter relatively to the curved blades *b*, and revolves in a partially closed casing *c*, so that the skin or frame *d*

of the aërial machine is tangential to the boss *a*. The direction of the arrows indicates the direction of the air current. It has not yet been deduced from experiment or demonstration that a real gain is effected in the work

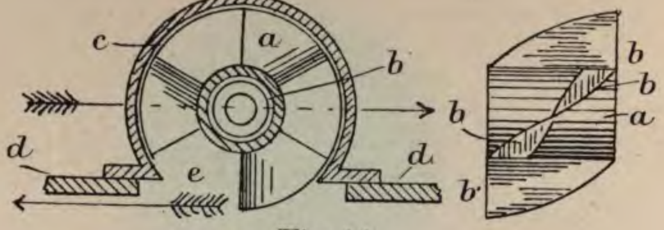

Fig. 44.

done by a propeller by enclosing it peripherally in an immobile casing. It is an undoubted advantage to obtain the full value of the reaction thrust.

This has more or less been provided for by Vogelsang,

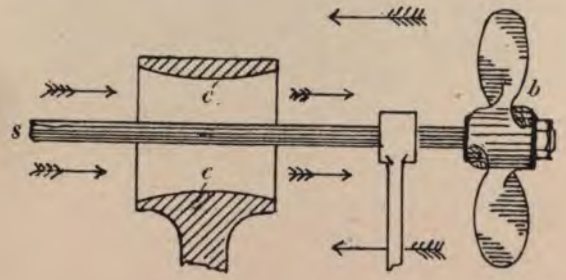

Fig. 45.

as shown by Fig. 45. Here, in front of the propeller *b*, revolving on the shaft *s*, and concentric therewith a portway mounted upon a bracket, and contracted at the central cross section *c*, so that the air displaced by the

revolution of the propeller *b* may, in rushing through the contracted portway, set up a reaction which materially assists propulsion.

The difference in the density and behaviour of displaced air in the case of effecting propulsion by screw

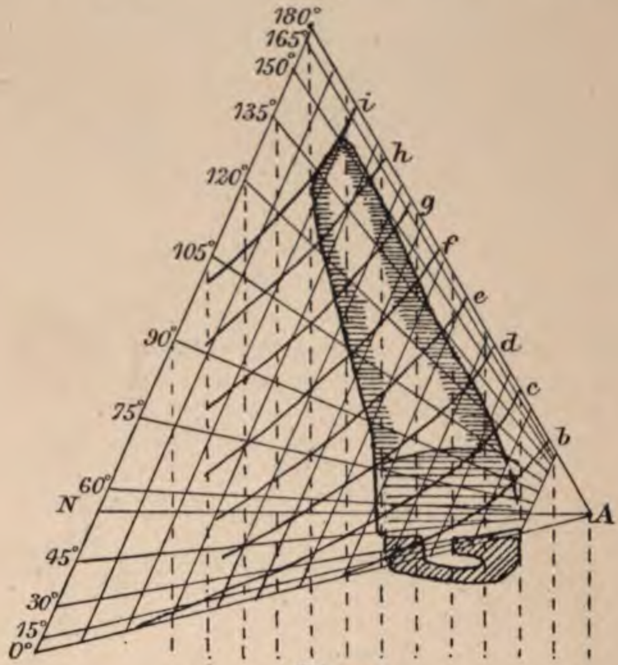

Fig. 46.

propellers relatively to water as a medium has given rise to the inception of various kinds of screw to produce the required effect with due regard to the elasticity of the air. Some inventors rely upon a rigid structure, carefully plotting the curves comprised in the blades to displace, and at the same time to utilise the comparative

solidity due to the reaction of the mass. Others, again, depend upon automatic adjustment according to the air resistance against some form of elastic spring, in some cases applied to otherwise rigid blades, and in others adopting an elastic structure for the blade itself upon a boss which is immobile except for its revolution upon its axis.

The construction of a screw propeller in which the face of each blade is a portion of the surface of a cone, the axis of which is inclined to the surface of the shaft, is shown in set-off by Fig. 46. The pitch lines *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i* are the intersections of the conical surface with cylinders concentric with the axis AN of the propeller, the relative angles being shown as from 0° to 180°. This type is generally known as the Adams propeller, and may be formed with semi-elastic blades of sheet metal pressed into shape by inverse templets constructed upon the lines set down in the diagram. Another type of semi-elastic propeller is that of Pennington and New (Fig. 47), in which a radial rib of steel *b* has a heavy curved head *c* forming the periphery of the propeller and also acting as a fly-wheel. The surface or web *a* of the blade may be made of thin sheet metal, wood, or with edges of semi-elastic, light material, and filled in with fabric of some suitable texture.

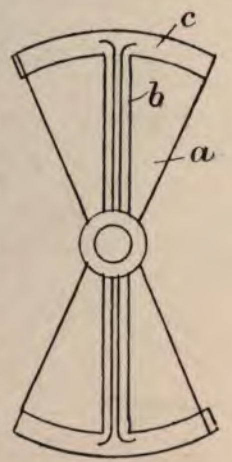

Fig. 47.

An example of the mobile type of blade is that of Heathorn. The propeller blades *v* shown by Fig. 48 are mounted upon a hollow boss upon a shaft cranked

oppositely at *c*, *c'* and common to both opposite blades. Stout elastic bands *y* of rubber, or steel springs, tend to maintain by their tension the cranks *c*, *c'* in close proximity to fixed pins *z*, which are coupled to the cranks by the bands or springs *y*. The blades *v* thus resist the angular inclination in rotation automatically, and adapt such inclination as may be induced by the

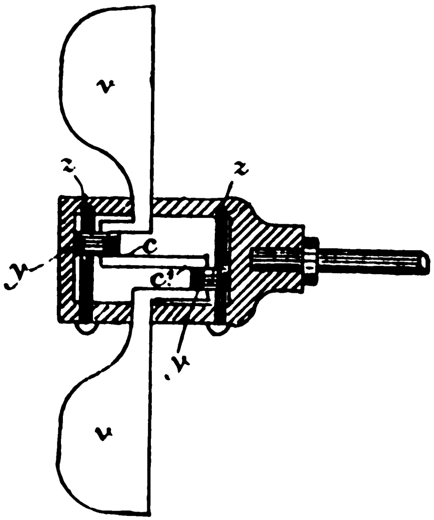

Fig. 48.

velocity. It is obvious that a considerable loss of power must result from an indefinite angle and variable pitch, especially in the case of high velocities.

Razeau's propeller is of the multivane type, and is shown by the two views, Fig. 49. A number of helical blades *a*, *b*, *c*, *d* are attached to a large boss B on the shaft K to form the screw propeller; the outer edges of these may be free, or are attached to a conoidal ring or

hoop *de*. Curved surfaces *f*, *g*, H, and *l*, *m*, are fixed to the shaft K, one on each side of the propeller, to deflect the currents of displacement to the blades, and recombine them so that all the energy due to reaction may be utilised in propulsion without undue shock due to intermittent impulse.

Paddle Propellers.—The use of paddles in aërial propulsion is not broadly advocated for the reasons that as a means of displacing air and utilising the

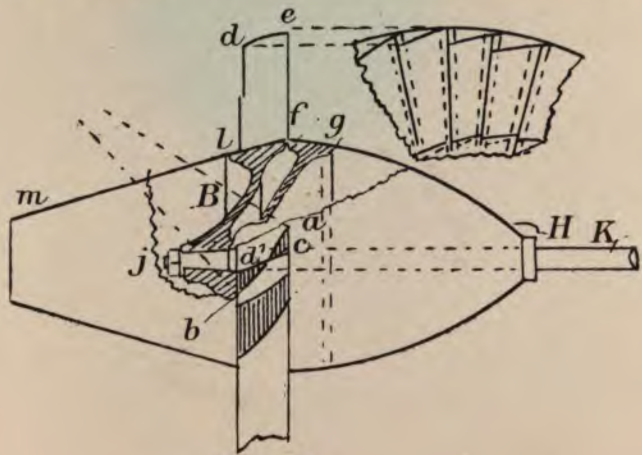

Fig. 49.

reaction of the induced currents, the necessary high velocities cannot be sustained effectively, since the feathering motion of the paddles, an essential function, at all times attended with considerable friction in the moving parts, is retarded by the action of centrifugal force upon the fulcrums of the vanes. This is negligible at low rates of speed, but as high speed is indispensable it is a decided disadvantage. An open paddle with radially fulcrummed vanes is impracticable unless the

leverage upon the axis is varied considerably during its rotation. That is to say, an ordinary feathering paddle wheel must be partially cased, or if the wheel is open the feathering action must be modified so as to reduce the radius of the leverage. Two examples are shown illustrating both methods. First, Oetling's feathering paddle, shown by Fig. 50.

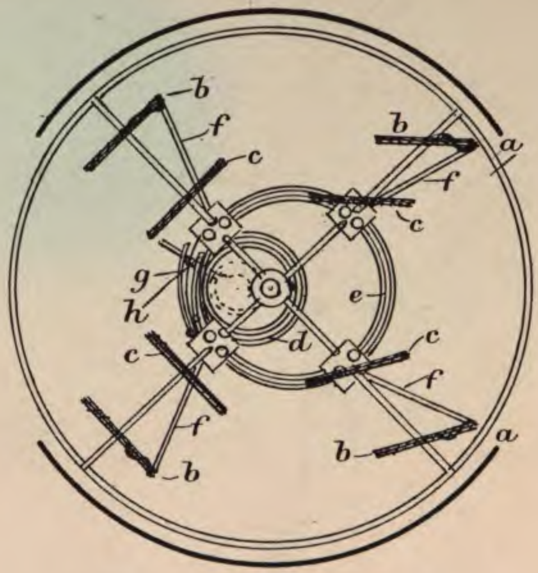

Fig. 50.

In this device the wheel revolves in a partially open casing *a*, and the vanes *b*, *c* are pivoted upon the arms, and are feathered by turning them once about their axes for every two revolutions of the wheel. This is accomplished by means of two eccentric cams *d*, *e*, into which the inner ends of the arms *f* are directed alternately by tongues *g*, *h* engaging in the grooved cam

paths. The openings in the casing *a* may be regulated by suitable doors. In Martin's wheel, shown in elevation and plan by Fig. 51, the blades are pivoted at *d* to a revolving boss *c*, and carry riding irons *g*, *h*, which ride on a cam *f*, and shift the blades from the right hand in which they make their down-stroke, the propelling

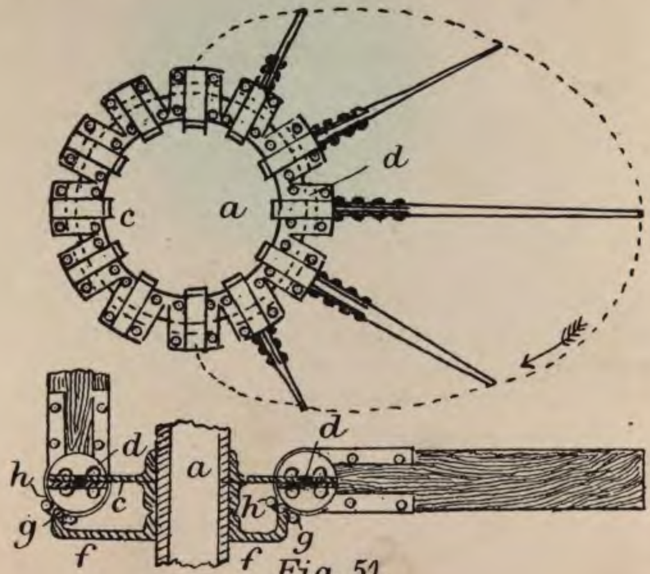

Fig. 51.

position, to the left hand, or idle position, in which they make the up-stroke.

Jet Propulsion.—Many inventors have sought to effect aërial propulsion by pressure jets, of steam, gases, or the reaction of explosion. The point at which the jet issues, a nozzle, for instance, is of small area, so that the area of displacement is also small where the maximum pressure is available by impact to produce

motion. The fluid issuing from the nozzle at a high pressure expands as an inverted cone of which the apex is the orifice. The volume thus increases and the pressure diminishes in inverse ratio, thus the effective work done may be estimated by the displacement of air in proportion to the volume of the cone at the mean pressure in a given period of time. If the pressure is derived directly from a steam generator, it is a wasteful method of utilising the initial energy; and if from a storage reservoir, the waste is greater, since power has to be employed to store gas under pressure. The system is equally inefficient when surfaces are added to utilise the energy of reaction, whether with single or multiple nozzles. It is equivalent to an attempt to convert a gun carriage into a locomotive vehicle by employing the energy of the recoil due to successive discharges as a motive power. Therefore, among the many recorded but unsuccessful experiments in this direction there are none to which we can refer in detail.*

Aeroplanes.—Probably the lifting power of a kite, and the pull exerted upon the cord, originated the idea of a plane surface suitably inclined so as to rise when a forward movement is imparted to it, and maintained during the flight. It has been amply demonstrated that a suitably designed aëroplane will rise in the air, and carry its load, but no extended flights have hitherto been accomplished. There is, in such a machine, a considerable inert mass which is unavoidable, and thus

* The only way in which a jet can be used with any degree of efficiency, is to employ it within a trumpeted casing so that it may, by its initial velocity, set up a lesser velocity in a larger volume of air which may appreciably react upon the surrounding atmosphere to cause motion. The analogy in this case is that of the steam pressure ejector, and not that of the oft-quoted H.M.S. *Waterwitch.*

when once in the air, at the mercy of every variation of the wind currents, the maintenance of equilibrium must be automatic, involuntary and anticipatory as it were, as in the action of a man standing or walking, or a bird soaring. This attribute is yet in the future, so far as mechanical action is concerned, whether automatic or under human control. The larger motive aëroplanes have been provided with a railed track, to attain the

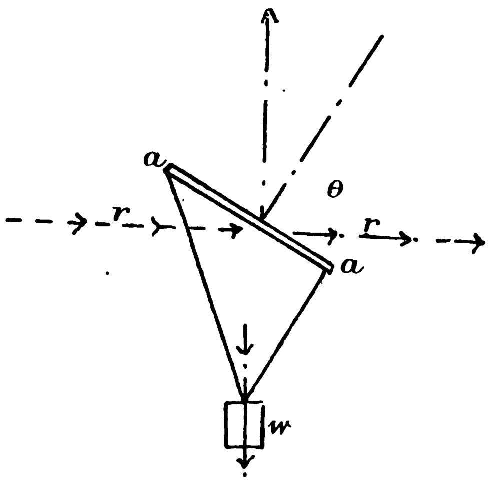

Fig 52.

required velocity previous to actual flight. An upper rail restrains the tendency to premature ascent. No provision has been made as yet for descent in the open country or elsewhere, nor is the direction of motion capable of being diverted far from the point from which the wind is blowing. We shall presently find, when dealing with the construction of an air-ship which alone renders aërial navigation possible, that the aëroplane, if

impracticable as a means for flight used alone, is a valuable accessory to the air-ship.

Before entering into the subject of the aëroplane and its development, it will be well to consider the action of the wind upon an inclined surface at rest. Referring to the diagram, Fig. 52, let *a* be an inclined surface at rest, *r* the wind pressure, *w* a suspended weight, and θ angle of inclination to the wind, and p pressure of wind per square foot at normal, *i.e.*, if the

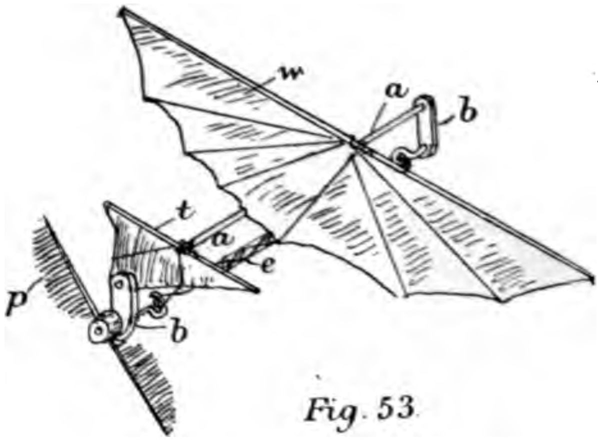

Fig. 53

surface was directly opposed to it instead of being inclined. Then the resultant pressure per square foot on the oblique surface P is—

$$P = p \times \frac{2 \cos \theta}{1 + \cos^2 \theta}$$

and $p = .005v^2$ in miles per hour,
or $p = .0023v^2$ in feet per second.

So the value of the lifting power upon w may be calculated if the area of the plane a is defined in square feet, or the weight of w in pounds if it is raised.

M. Pinaud carried out many experiments in motive aëroplanes, one of which, a toy, is a modification of Sir George Cayley's device shown by Fig. 53. An aëroplane *w* and *tail vane t* are attached to a frame *a*, between the ends *b*, *b'* of which is stretched a twisted rubber band *e*, which, when wound up in tension, rotates a propeller *p*, affording a sustained oblique flight.

Mr Wenham devised a multivaned aëroplane, in which the lifting vanes were superimposed upon each other similar to a set of bookshelves. This doubtless

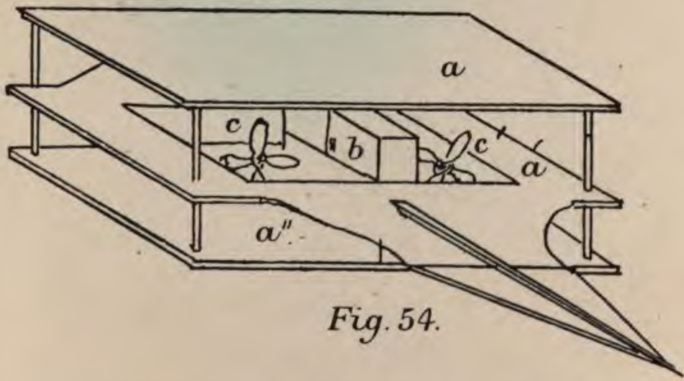

Fig. 54.

has developed into the "box" kite in use for military purposes. Stringfellow improved upon this apparatus in 1868, adding motive power and screw propellers, and his machine is illustrated by Fig. 54. The planes *a*, *a'*, *a''* are superimposed as in Wenham's device, and the generator and motor *b* fixed on the lower plane *a''*, the propellers *c*, *c'* revolving through spaces formed in *a'*, which also carries the prow and tail vanes. The total weight was only 12 lbs., inclusive of the water required to generate the steam, although the power developed was 1.3 H.P. A trial took place at the Crystal Palace

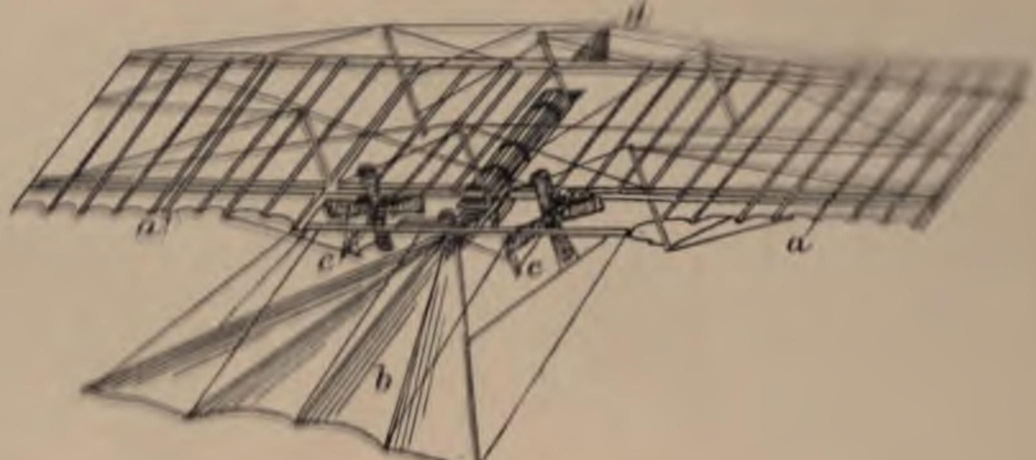

Fig. 55.

under the auspices of the Aëronautical Society of Great Britain, and Mr Stringfellow obtained an award of £100 on account of the lightness and efficiency of the motor apparatus. The apparatus ran upon an extended wire, and although the machine travelled at a high rate of speed, it did not leave the wire.

Henson at the same time made a large aëroplane

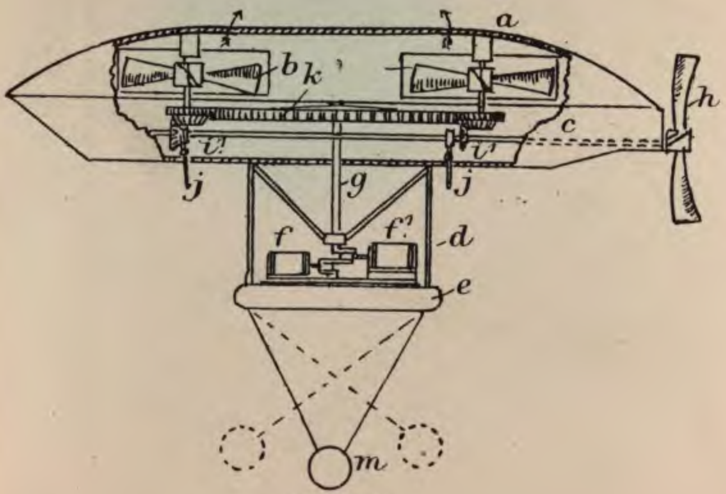

Fig 56

shown by Fig. 55, in which the horizontally extended planes *a*, *a′* were 40 ft. from end to end. A cigar-shaped car *d* carried the motive power apparatus for operating the screw propellers *c* and also the aëronaut. Steering was effected by a tail vane *b*, and broad-tyred wheels were fitted below the car to carry it while the initial velocity was attained previous to ascent, and also to facilitate landing when descending. This made several

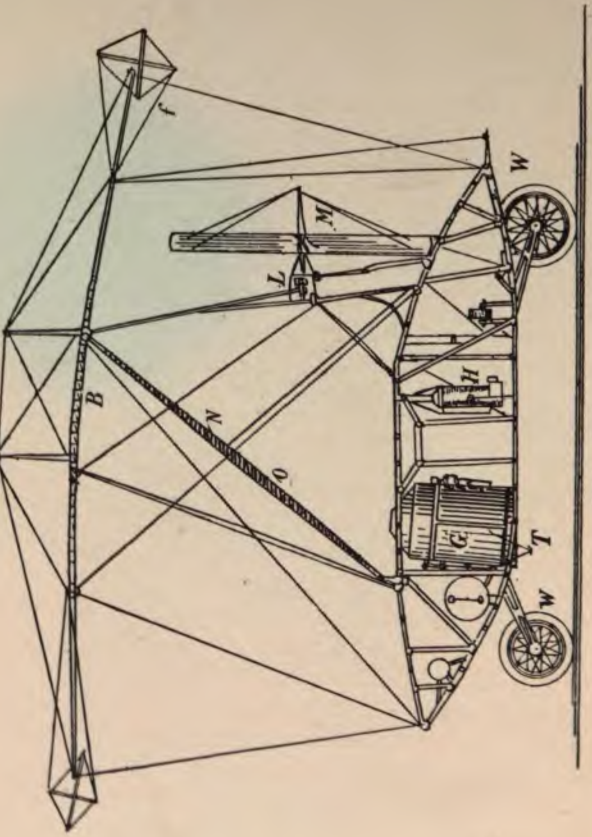

Fig. 57.

flights of short duration, but was generally a failure for the reasons we have previously explained.

In Crease's aëroplane the lifting planes are merely adjuncts, the actual lifting being accomplished by screw propellers with vertical axes. This device is shown by Fig. 56, in which an aëroplane *a* has a light framework covered by fabric. A deep keel *i* supports a tubular platform or car *d* having a hollow base *e* for storing the liquid fuel or gas under pressure. Two motors *f*, *f′* on the platform *d* drive a vertical shaft *g* which transmits the power by means of a spur wheel *k* and pinions to two propellers *b*, over which two orifices are formed in the fabric of the aëroplane for the emission of the displaced air. A stern propeller *h* controlled by clutches *j*, *j* affords horizontal propulsion, and steering is effected by changing the position of the balance weight *m* as shown by the dotted lines.

Sir Hiram Maxim has carried out extensive experiments in dirigible aëroplanes, and in the course of developing his ideas, has been successful in producing effective motors and generators of extreme lightness and portability, which will be noted under the head of Motive Power in a succeeding chapter.

In one of Maxim's machines (Fig. 57) the aëroplane B is trussed and stayed with wires, and covered on both sides with fabric, which is stretched tight on the under side, and is perforated for the air to pass through, so that the weight is supported by the top surface. The lifting planes N are arranged step-wise as shown, and made long and narrow, and in some cases hollow to form a surface condenser, and are supported by bowed tubes O, carrying the exhaust steam and condensed water. The motor L drives the propeller M by steam pressure from a generator G. A vaporiser H is connected to a suitable burner T under the generator G. The whole is supported

when at rest upon wheels W, and steered in flight by sail rudders *f* fixed on pivots to B, fore and aft.

In another machine, constructed by Maxim, and shown by Fig. 58, the main aëroplane *a* is pivoted upon a vertical support b^2 carrying a car *b* mounted upon wheels *f*, and the inclination of *a* may be adjusted and regulated by suitable ropes, pulleys, and a winch. Wings may be attached to *a* to which a downward motion is automatically imparted by the impact of the wheels *f*

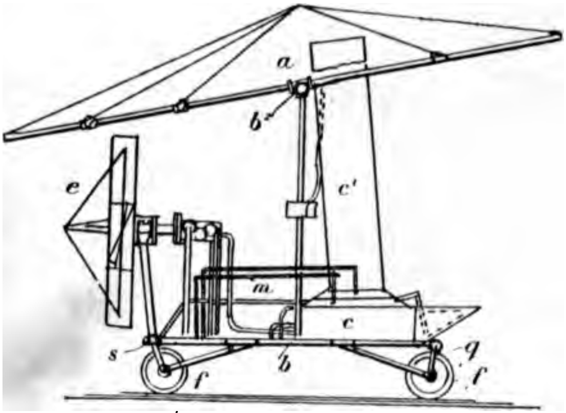

Fig. 58.

upon the earth in descent, the arms *q* being connected to drums *s* for that purpose. Light screw propellers *e* are rotated by engines driven by the pressure generated in a boiler or other generator *c*, a chimney *c'* carrying off the products of combustion, pipes *m* conveying the vapour or gas under pressure to the engines. A supplementary condenser of the flat film type is added to the tubular framework, and by its structure may form part of the sustaining planes of the apparatus.

Sir Hiram Maxim has further modified his aëroplane

in the manner shown by Fig. 59, in which the machine is supported in the air by two large screw propellers, one upon each side, driven by nearly vertical shafts. One of these screws C^1 is shown in the elevation. It is four-bladed, and is of small pitch. The shaft *b* is slightly inclined from the vertical in a forward direction, and is driven by the four-cylinder steam or gas engine D. The blades of the screws are stayed so as to automatically diminish the pitch as the air pressure below them increases. The leading edges of the screws C^3 are stayed to a fixed

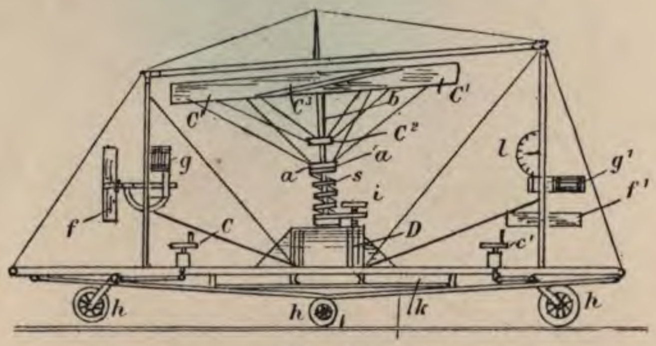

Fig. 59

collar C^2 upon the shaft *b*, and the rear edges to a sliding collar *a* attached by a spring *s* to the bearing collar, and controlled by a hand wheel *i*. The frame is mounted upon three wheels *h*, the leading and trailing wheels being adjusted in height by means of hand wheels *c*, *c'*. In addition to the large screws already described, the machine also carries two smaller screws *f*, *f'*, one in front and the other behind. These are mounted with their motors *g*, *g'* on trunnions, so that the screens may be either lifting, lowering, or propelling, and are preferably, like the lifting screws C^1, made of a light metal frame-

work, and covered with strong fabric. In starting the machine it is run forward upon the wheels until the screws C^1 exert their effect in lifting the apparatus, and act in the manner of aëroplanes or wings. The loose collar *a* and spring *s* admit of a feathering action by presenting the least surface in front. Rolling is counter-

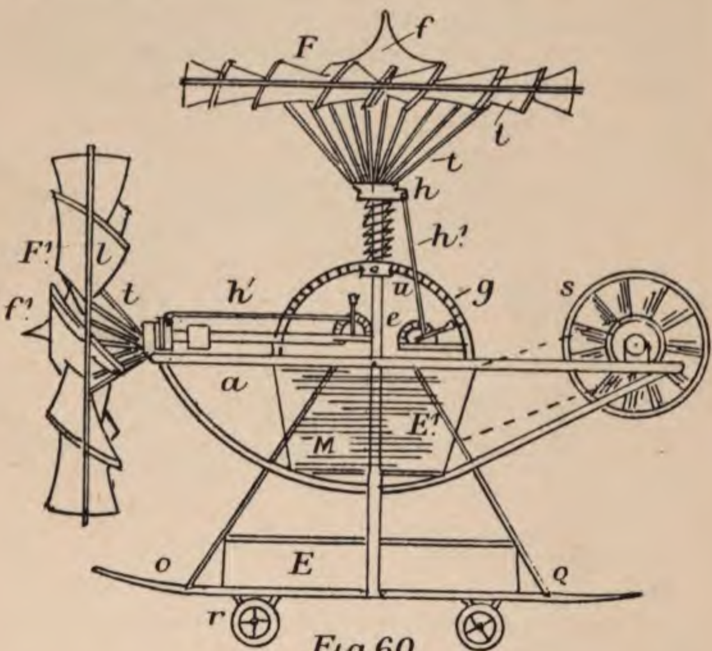

Fig. 60.

acted by the automatic action of a weighted pendulum which cuts off the motive fluid from the engine on the rising side, and giving a full supply to that upon the lower side. Fore and aft balancing is effected by a sliding platform controlled by a hand wheel. The motors D have four cylinders arranged in pairs opposite

one another and driving cranks at 180°, so that with a four-stroke cycle an impulse is obtained every half revolution. The motors are preferably driven by acetylene, which is stored in reservoirs *k* and mixed with about $\frac{1}{50}$ by volume with acetone or acetic ether to produce a mixture which can be kept liquid at a lower pressure than acetylene alone. The tubular framing may be utilised as a condenser.

Beenen follows this mode of construction in the apparatus shown by Fig. 60. Two cars E, E′ are used, the former for passengers and the latter for carrying the motor M (not shown). A lifting screw F and horizontal propelling screw F′ are adapted to the frame, and driven by suitable gearing by the motor. The machine is steered by means of a fan or propeller *s*. The shafts of the lifting and propelling screws F, F′ may be inclined so as to allow the screw F′ to assist in lifting, the collar *u* being adjustable around the quadrant *g*. The screws F, F′ are constructed with a hollow conical centre *f*, *f*′, and a ring of vanes made concave on the pressure side are pivoted in radial bearings. The inclination of these blades *l* can be adjusted by rods *t* joined to a sliding collar *h*, the position of which can be regulated by a sliding collar *h*, rod *h*′, and handle within a suitable quadrant. Wheels *r* and runners *o* are provided to facilitate movement upon the ground in ascent and descent.

Davenport constructed an aëroplane shaped like a bird, the body being the car, and carrying the motive power apparatus. The wings were rigidly attached to the body, and of great superficial area. The wings were strongly made in two layers superimposed with a space intervening. The lower surface was of open framework, carrying a number of fans with vertical axes, and driven by the motor through bands, or rope gearing. The upper surface was slotted and provided with valves at

close intervals, which closed automatically by pressure underneath, but freely opened under top external pressure. A large tail vane effected the vertical and horizontal steering, and the mode of progression was to ascend vertically, and glide forwards and downwards, and this process being repeated, propulsion was effected.

The aërocurve is a formation of the aëroplane proper, in which the latter is stepped into a series of curvilinear surfaces, derived from a cissoid, the upper or passive surface being parallel to the asymptote thereof. It is a complicated and somewhat expensive mode of construction, but when the opposing angle is between 7° and 15° at a velocity of 88 ft. per minute, the retardation due to the shape and angle gives a lifting power of .00397 lbs. per square foot, and proportionately according to v^2.

CHAPTER VI.

MOTIVE POWER.

IN dealing with the subject of motive power, we must bear in mind that the construction of any motor, generator, and storage apparatus must afford the maximum of effective power at a high rate of speed, and the minimum of weight. We may divide the various types suitable for the purpose under the following heads, viz., vapour engines (explosive), such as petroleum and other internal combustion motors; steam engines (water or spirit vapour), generators, electric motors and accumulators, and motors operated by compressed air or gases stored in reservoirs.

Fuel.—In the first place, we may compare the value of fuels as adapted for storage, consumption, and application to aërial navigation. Coal and solid fuels are not adapted to close storage, and the calorific power is far below that of liquid fuels. The three units of heat now in use are the B.T.U. (British thermal unit), being the amount of heat required to raise 1 lb. of water 1° Fahr. This unit is in ordinary acceptance in this country, but to facilitate general research we may give the equivalent values of the P.C.U. (pound Centigrade unit), the amount of heat required to raise 1 lb. of water 1° Cent., and the cal. which is the amount of heat required

to raise 1 kilogram of water 1° Cent. The conversion factors are—

Convert	B.T.U.	into	P.C.U.	× 0.555
„	B.T.U.	„	Cal.	× 0.252
„	P.C.U.	„	B.T.U.	× 1.8
„	P.C.U.	„	Cal.	× 0.3423
„	Cal.	„	B.T.U.	× 3.968
„	Cal.	„	P.C.U.	× 2.921

The combustion of a hydrocarbon occurs when the temperature is sufficient for the heat evolved to produce luminosity, and complete combustion takes place when the highest point of oxidation is reached. Incomplete combustion is shown by unconsumed by-products, and the escape of the gaseous residue at a low degree of oxidation. For instance, the by-products should consist only of water and carbon dioxide (CO_2), and the result of inefficiency is the presence of soot as a solid carbon by-product, and free hydrocarbon or carbon monoxide (CO) as a gaseous by-product.

The following table shows the values in B.T.U. of various fuels and constituents, upon the basis of Pullen's calculations :—

Solid Liquid or Gas.	Atomic Weight, H = 1.	Density, Pounds per Cubic Foot.	Specific Heat, Constant Pressure.	Specific Heat, Constant Volume.	Molecular Weight, $H_2=2$.	B.T.U.
Air - - -	...	.0809	.2377	.1690	...	...
*Carbon - -	11.97	108.7	.2411	...	...	14,540
Carbon dioxide -	...	.1225	.2164	.1535	CO_2.43.9	...
Carbon oxide -	...	.0784	.2479	.1758	CO.27.9	4,370
Coal gas - -	...	.0335	...	...	...	17,800
Hydrogen - -	1.00	.0056	3.404	2.414	H_2.2	61,260
Nitrogen - -	14.01	.0784	.2440	.1730	N_2.28	...
Marsh gas - -	...	.0448	.5929	.4701	CH_4.15.9	26,400
Olefiant gas -	...	.0784	.404	...	C_2H_4.27.9	21,300
Oxygen - -	15.96	.0896	.2182	.156	O_2.31.9	...
Steam, 212° -	...	.05	.4750	.34	H_2O.17.9	...
Sulphur - -	31.98	.127	.2026	...	S_2.63.9	4,000
Sulphur dioxide -	...	.1792	...	...	S_2O.62.9	...
Petroleum, refined	...	52.61	...	...	...	22,000
,, crude	...	54.3	...	...	...	20,000

* This applies to approximately pure carbon—graphite.

Petroleum in most of its many forms has theoretically, weight for weight, 33 per cent. higher evaporative value than the best steam coal. Its useful effect is 15 per cent. greater than that of anthracite, which is the best known kind of steam-raising coal, since petroleum can be reckoned as 75 per cent. efficiency instead of 60 per cent. So, to sum up, petroleum may, weight for weight,

be practically considered as from 63 to 75 per cent. higher than the best coal.

The following table shows the comparative values of petroleum, fuel, and coal :—

FUEL.	Specific Gravity, 32° Fahr.	B.T.U.	Evaporation Pounds Water at 212° Fahr.
Best steam coal - - -	1.380	14,112	12.16
Refined petroleum - -	0.928	17,832	17.10
Caucasian heavy crude -	0.938	20,850	17.30
Caucasian light - - -	0.884	22,027	22.79
American crude - - -	0.886	20,736	21.48

Therefore we may assume that for purposes of aërial navigation liquid petroleum fuel will be preferably used.

Generators.—The requirements of the equipment of an air-ship demand the maximum amount of power with the minimum of weight, therefore the tubular form of construction appears best to meet the circumstances. A relatively small and continuously injected volume of fluid and a restricted steam space renders the generator rather a rapid high-pressure gas producer than a steam boiler. Sometimes a volatile liquid is employed, the boiling point of which is less than that of water, and the tubular structure of the frame of the aërial machine is utilised as a surface condenser, with an auxiliary condenser if necessary. The disadvantages are in the difficulty of efficiently packing the glands and stuffing boxes of the moving parts, the vapour being extremely *rarefied*, and permeating freely what would be a steam-

Fig. 63.

Fig. 62.

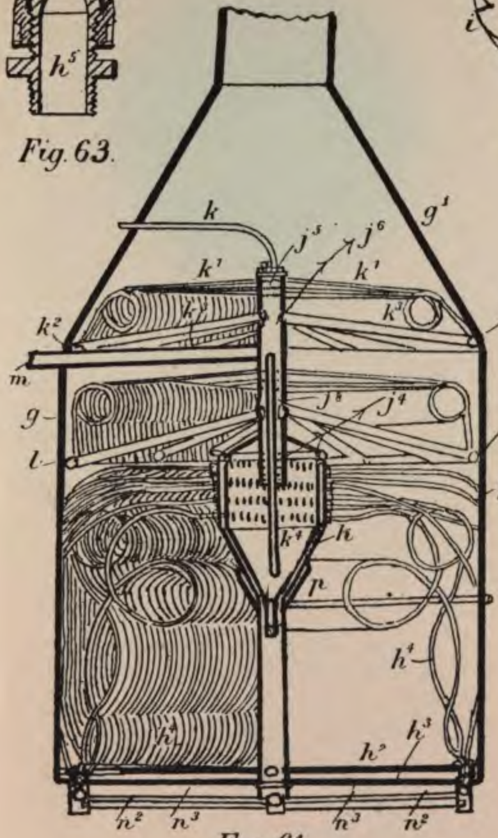

Fig. 61.

tight joint; and the leakage is also attended with danger, as its admixture with atmospheric air is highly explosive. If, on the other hand, absolutely pure or distilled water is not maintained in the circulating system, scaling takes place to the detriment of the tubes, and the nature of the construction does not allow of any cleaning process but by the use of a chemical solvent, which is in itself a source of degeneration.

We can, within the limited space afforded, only give examples of the best generators suitable for the purpose, making no comparisons advocating or depreciating any particular design.

Maxim's generator is shown by Figs. 61, 62, and 63. The medium may be water, or gasoline or other liquid hydrocarbon that is volatilised at a low temperature. This is supplied through a feed pipe k to the boiler g, leading through a chamber j^5, pipes k^1, k^2, k^3, a chamber j^6, and pipes k^4 to the bottom of a central chamber from which it forces by induction the re-condensed vapour into the heating pipes h^2 above the heater n^1, n^2, n^3. The vapour passes from the annular pipe h^3 through tubes h^4 into the annular space between the chamber h and the central chamber i, from whence it passes to the latter chamber tangentially through suitably formed orifices i^3, Fig. 62, to chamber j^4, pipes l, l^1, l^2 to another chamber j^8, from which it passes to the engine by the steam pipe m. The tubes h^4 are connected to the pipe h^3 and chamber h by specially constructed unions, consisting of a conical screwed nipple h^5, Fig. 63, and a corresponding nut h^7. The tubes n^1, n^2 and deflectors n^3 of the burner are made of nickel or an alloy of nickel and iron. The supply of gas or vapour is regulated automatically by the boiler pressure or by the temperature, the latter of which acts by the expansion of water in a chamber p, forming an annular jacket to h. The heating surface in this type of

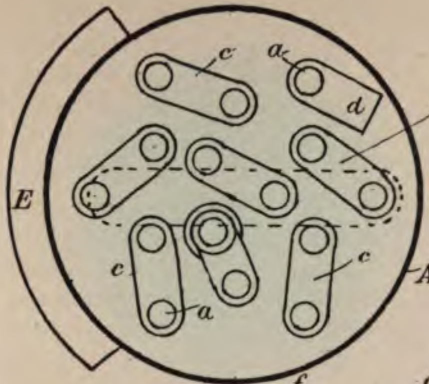

Fig. 64.

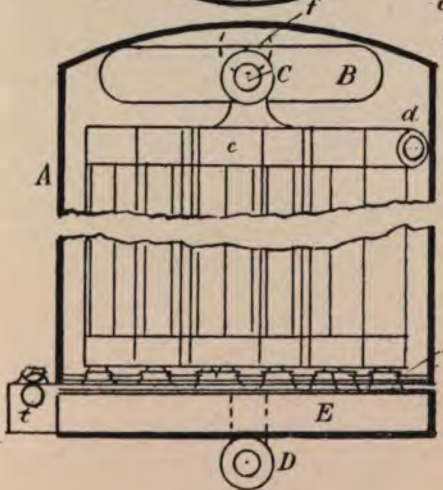

Fig. 66.

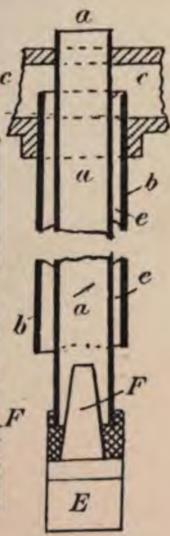

Fig. 65

generator is very great, and consequently the liquid and steam spaces are restricted, requiring a constant feed.

Another generator, preferably for water produced steam pressure, is shown by Figs. 64, 65, and 66. It is the combined result of several inventions, and therefore cannot be classed as a distinctive apparatus. It consists of an outer shell A, at the base of which is a hydrocarbon vaporising chamber E provided with a number of Bunsen burners F. A number of tubes *b* are fitted with specially constructed tee unions *c* at each end, so that a uniform fluid circulation may be obtained from the inner to the outer ring of tubes. Central tubes *a* pass through the middle of the outer tubes, and also through the unions *c*, and these form the outer tubes of the Bunsen burners F, the heat from combustion passing through and heating the inner surfaces of the tubes *a*, and being diverted by diaphragms or baffle plates (not shown) passes downwards, thus heating the outer surfaces of the tubes *b* before passing to the atmosphere by the orifice *f*. The system is kept full of fluid by a constant and regulated feed at D, the steam passing from *d* to a steam reservoir or holder B, from which it is taken to the engine by the steam pipe C. Thus the annular capillary space *e* between each inner tube *a* and outer tube *b* presents a large surface for heating a comparatively small volume of fluid. The liquid hydrocarbon fuel is supplied under pressure to E by an inlet *t*. The drawing, Fig. 65, being to a larger scale, illustrates the arrangement of the two tubes.

Another form of generator designed by Maxim is shown by Figs. 67 and 68. This consists of a large number of thin metal tubes A of small diameter, connected with larger tubes A^1 forming headers or water chambers, and arranged in tiers as to the upper part, but entirely surrounding the furnace at the bottom. The

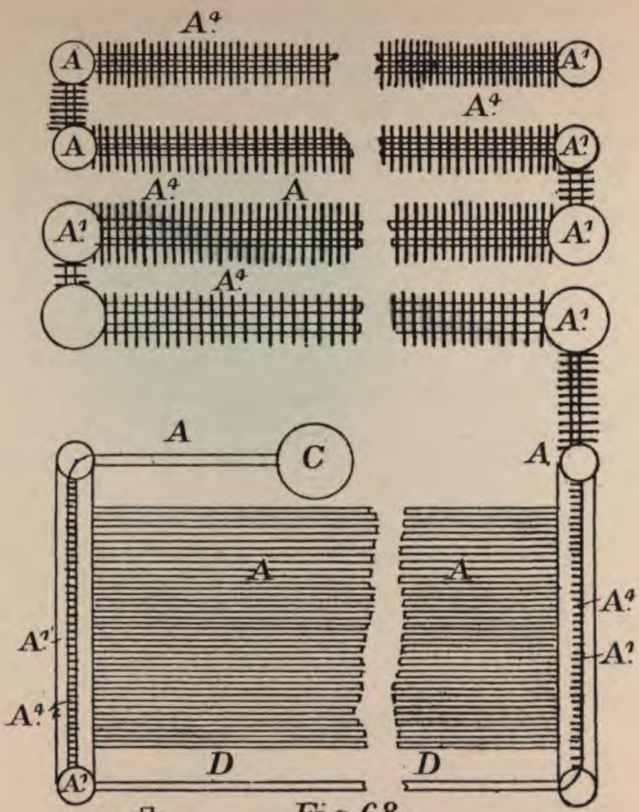

Fig. 68.

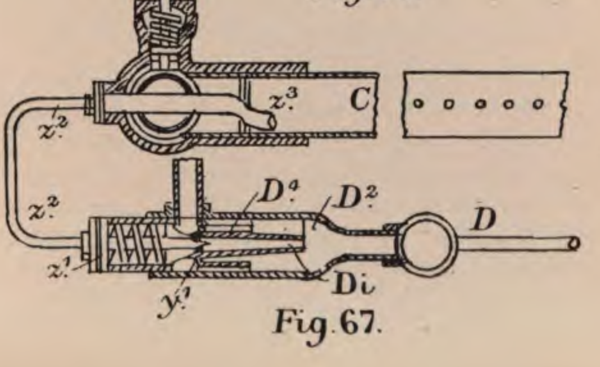

Fig. 67.

tubes are furnished with ribs or wings A[4] for facilitating the transfer of heat. The headers A[1] are divided so that the water which is forced in by pumps follows a sinuous course from the cooler to the hotter portion of the furnace, and finally delivered into a steam drum C completely vaporised. The capacity of the generator is sufficient for effecting a few strokes of the engine only,

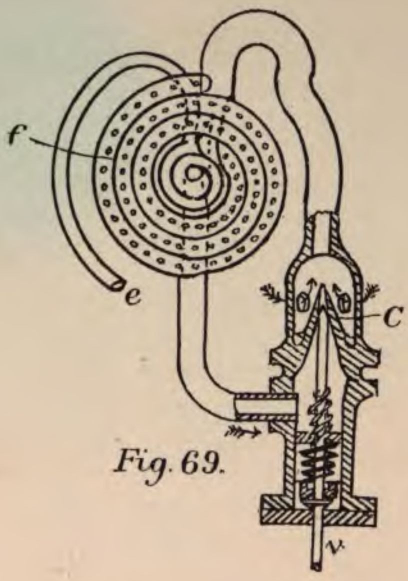

Fig. 69.

and the circulation of water is provided for by the exhaust, which is condensed and used continuously. The generator is heated by liquid or gaseous fuel, which with the water is supplied by a combination of pumps in predetermined relative proportions. The burners, shown detached in section by Fig. 67, consist of a series of *perforated* tubes D into which the fuel is forced along

with air by an injector D*i*, of which the fuel admission valve Y^1 is controlled by a thermostatic regulator. The air is admitted through openings in the casing at D^4, and the fuel after passing through a heat vaporiser is forced through the injector nozzle D^2 by a pump. The thermostat is fixed within the steam drum C, and consists of a closed tube z^3 containing a suitable liquid, and communicating by a pipe z^3 with a diaphragm z^1. The valve Y^1 is operated by the movements of the diaphragm z^1 against a coiled or spiral spring.

Barbe's heater is shown by Fig. 69, and is designed for liquid hydrocarbon fuel with any kind of generator having a large heating surface. The liquid enters by the pipe *e* and is vaporised at the centre of the burner, and passes in regular quantities through the injector C, controlled by the valve v, to the spiral tubular burner *f* which is perforated. A lamp or any suitable device is employed for igniting the jets.

Internal Combustion Engines.—These may be defined as engines in which the liquid hydrocarbon is vaporised within the engine, the supply being regulated with a corresponding air supply, forming an explosive compound when ignited by an electrical high-tension spark or heated tube. Hydrocarbons of low-flashing points are preferable in point of economy, but there are legal restrictions as to storage and transport in respect of public safety generally which militate against their use. From the heavier petroleum products we get a wide range of hydrocarbons, as the following table will show, the normal paraffins being specified.

Definition.	Symbol and Boiling Point.	Nature.
Methane - - -	CH_4 Gaseous	- Gas.
Ethane - - -	C_2H_6 ,,	Gas.
Prophane - - -	C_3H_8 ,,	Gas.
Butane - - -	C_4H_{10} 1°	Solvent for resins.
Pentane - - -	C_5H_{12} 38°	,, ,,
Hexane - - -	C_6H_{14} 70°	Illuminant and motive power.
Heptane - - -	C_7H_{16} 99°	
Octane - - -	C_8H_{18} 124°	Motive power.
Dodecane - - -	$C_{12}H_{26}$ 202°	Vaseline.
Hecdecane - -	$C_{16}H_{34}$ 278°	Paraffin wax.

Benzol, C_6H_6, is obtained either synthetically by heating acetylene, C_2H_2, to nearly a red heat, or by the destructive distillation of coal. Its boiling point is 80.5°, and it is frequently used as a liquid fuel, either alone, or in combination with other hydrocarbons.

The internal combustion oil engine, therefore, takes the liquid hydrocarbon, vaporises it by heat, mixes the air, compresses and ignites for an impulse to be given. There are many kinds of vaporising devices, which may be distinguished as—

(*a.*) Hydrocarbon liquid injected into a reservoir chamber, and mixed with the proper air supply therein by a spray, before admission into the cylinder.

(*b.*) Liquid injected into a small chamber with part of air supply, the rest of air entering the cylinder by

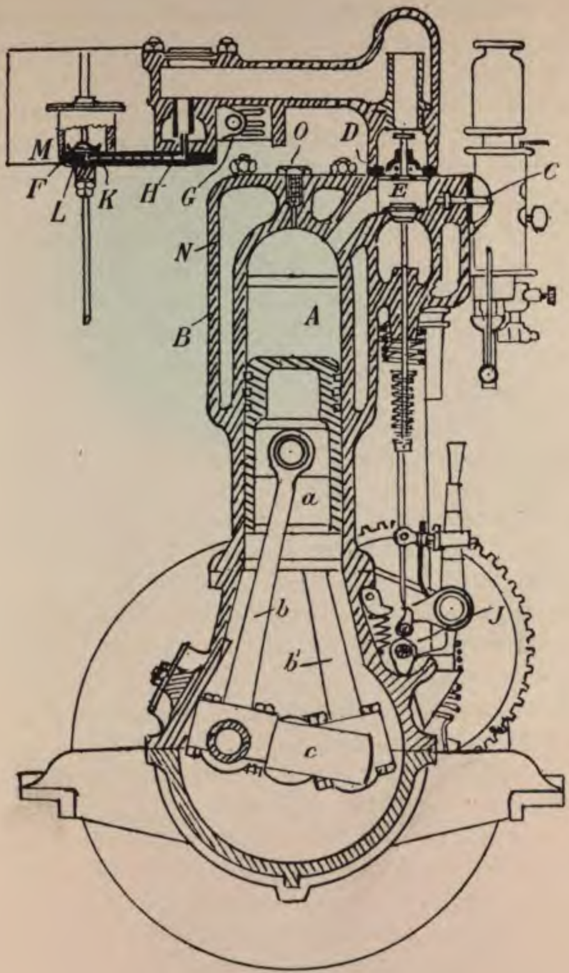

Fig. 70.

another valve. Therefore the contents of the vaporiser are inexplosive until after admission to the cylinder.

(*c.*) The same as (*a*), except that no air-spraying nozzle is used.

(*d.*) The liquid is injected directly to the combustion chamber, and there vaporised, and air is drawn in by the piston through a separate valve, and mixed in compression.

The Hornsby-Akroyd engine is constructed upon this principle, and although in practice this engine gives excellent results, the piston area is relatively large, probably by reason of the imperfect admixture of gases.

When considering the calorific values of liquid hydrocarbons used in this way, we must note that in the exhaust a volume of water is produced by the union of H and O, according to the weight of the percentage of hydrogen in the mixture. This amounts to a little over 1 lb. weight of water per pound of liquid hydrocarbon. The heat thus carried away must be deducted from the computation of the thermal value of the fuel.

There are many light motors of this type now in the market, but we can point out amongst them a few of the best adapted for the purposes of aërial navigation.

The Daimler engine, shown in section by Fig. 70, is of the two-cylinder vertical type. The liquid hydrocarbon is forced into the float chamber F by pressure applied to the reservoirs containing it in bulk. When starting the motor the air is pumped into the reservoir, but after running for some little time, a part of the exhaust serves to keep up the necessary pressure. Either ignition tubes heated by a lamp or electric spark ignition may be used.

On the down-stroke a slight vacuum is formed in the cylinder A. The valve E is held in place by a spiral spring, is operated automatically, and when open allows air to enter through the grating C and along the hori-

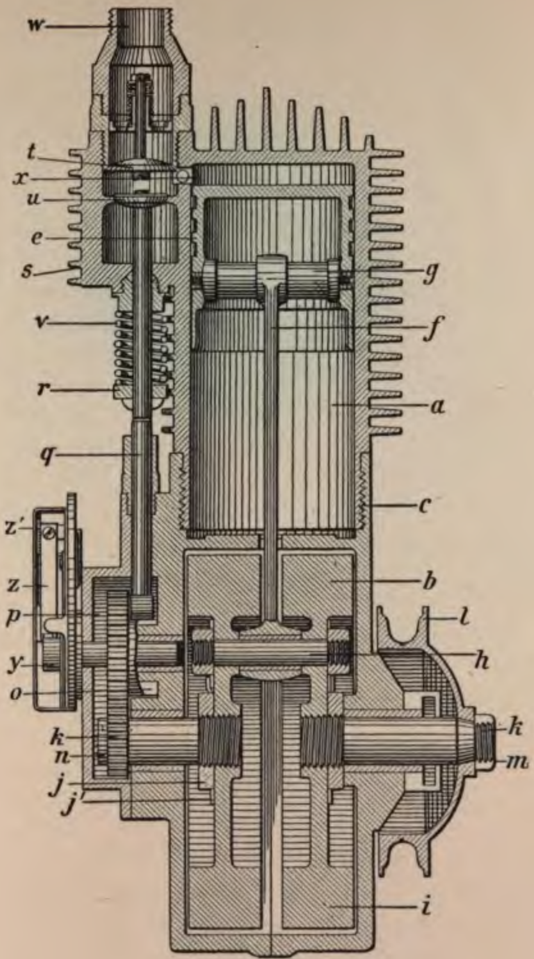

Fig. 71.

zontal pipe to E, and by thence to the cylinder. At the same time the liquid hydrocarbon is sucked through the nozzle at H, and mingles with the air in the cylinder to form the charge. On the up-stroke the compressed mixture is ignited at C, and a fresh impulse imparted to the piston *a*, and the exhaust released by the exhaust valve at E being actuated by a "hit-or-miss" striker worked by a cam J. The cylinders are water-jacketed at B. The connecting rods *b*, *b'* and crank *c* are shown in position. The Diesel engine is an improved device, since the charge of hydrocarbon is not introduced until the full charge of air has been compressed sufficiently in the cylinder, so as to be ignited directly the addition of the hydrocarbon completes the mixture. A corresponding test of a 20 H.P. Daimler engine by M. Holbert and 20 H.P. Diesel engine by Professor Schorter shows the relative efficiencies.

Daimler 20 H.P. engine—Diamèter of piston, 8.5 in.; stroke, 12 in.; speed, 200; brake horse-power, 16.9; indicated horse-power, 24.8; petrol, .053 lb. per I.H.P.

Diesel 20 H.P. engine—Diameter of piston, 9.8 in.; stroke, 15.7 in.; speed, 163 revs.; brake horse-power, 18.84; indicated horse-power, 26.31; consumption of hydrocarbon per I.H.P., 0.40 lb.

The Keelcom motor, with its special spray carburettor, is another excellent type of engine, having automatic action, and especially adapted for aërial navigation. The motor is shown in section by Fig. 71, and the carburettor by Fig. 72.

Referring to Fig. 71, *a* is the cylinder attached to the neck of the crank chamber *b* by screws *c*. The crank chamber *b* is made in two parts, and held together by bolts. The piston is shown by *e*, piston rod *f* and its fulcrum *g*, and the crank pin *h*. The cranks and fly-wheel discs *i* are secured to the crank shaft *j* by nuts j^1 and locking plate j^2. On one end of the crank shaft

j the driving pulley *l* is fixed by a key and nut *m*, the other end of the shaft carrying a pinion *n* gearing with a wheel *o* of the half-speed gear of the ignition device. To the wheel *o* is fixed a cam *p*, operating the stems *q* and *r* of the exhaust valve. The combustion chamber *s* contains the inlet valve *t* and exhaust valve *u*, *v* being the spiral spring controlling the exhaust valve. The inlet port is shown by *w*, and *x* is the combustion port to the cylinder. On the outer end of the shaft carrying

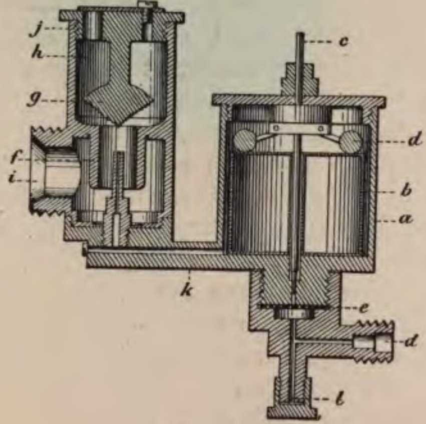

Fig. 72.

the half-speed gear wheel *o* is fixed a cam *y* which operates the contact breaker *z* forming part of the electrical ignition z^1. The carburettor is shown in section by Fig. 72. A float chamber *a* contains a float *b*, through which passes the needle valve *c*, the latter being held off its seat by the counterbalances *d*. The petrol inlet d^1 is covered by the wire gauze strainer *e*, and *f* is the spraying nozzle, *g* the atomising cone, *h* the mixing chamber, *i* the hot-air inlet, *j* the suction regu-

lating port, and *k* the connecting neck, *l* being a nozzle and cap for cleansing purposes.

These engines are compact, and work well and economically at high rates of speed, but as yet no certified test has been made. The choice of a suitable motor depends upon lightness relatively to power, and the comparative weight of fuel to last a reasonable time.

Electrical Motive Power. — There are scores of light motors of high efficiency especially adapted to aërial propulsion, but the storage of electrical energy is up to the present time prohibitive on account of the great weight to be carried, and the absence of convenience for re-charging except at certain places, unless accumulators of sufficient capacity for an out-and-home charge are provided. This may be obviated if a system of aërial navigation was once established, because every city or town of any importance would have a special charging station. It must be remembered as a set-off to the weight of the accumulators that no intermediate gearing is required between the electric motor and its work, since the propellers may be proportioned to the speed, and this again regulated within certain limits according to the design and winding of the motor.

In calculating electrical power we take E to be the potential or electro-motive force, and C the current or flow in ampères, using simple phraseology. Then

$$E \times C = W$$

where W means work or electrical energy in watts. Then

$$\frac{W}{746} = \text{E.H.P. (electrical horse-power).}$$

Assuming then that 10 E.H.P. is required for five hours, say at an E.M.F. of 120 volts and 62 ampères.

$$10 \text{ E.H.P.} = \frac{120 \text{ E} \times 62 \text{ C}}{746} = \frac{7460}{746}$$

Then as each accumulator cell is equal to 2 volts, 60 cells of the lightest pattern are required, and these weigh, inclusive of the electrolyte (sulphuric acid diluted 1 to 11), 68 lbs. each, or 4,080 lbs. or 2 tons with accessories, and with 19 plates will give a discharge of 300 ampère hours. Compare this with the steam or hydrocarbon engine, taking a mean of the former at 0.9 lb. per horse-power per hour, and 0.8 lb. per horse-power per hour for the latter. When an efficient substitute for lead of much less weight is found to produce the same storage effect by electrolysis, electricity will be found to be the form of energy best suited to air propulsion, but no advance in that direction has hitherto been successful.

But in cases where several propelling shafts are to be driven by the prime motor or engine, and these have their axes arranged in several planes, no more efficient intermediate gear can be devised than a dynamo generator driven by the engine shaft, and operating motors to rotate each propeller independently. In this respect, light, compact, and efficient propelling mechanism may be made by the proper utilisation of electrical energy.

CHAPTER VII.

STRUCTURE OF AIR-SHIPS AND MATERIALS.

WHEN we review the march of scientific knowledge and practical development that renders the elements subservient to advancing civilisation, we cannot see a single instance in everyday life that has not been built up of failures. The fast express trains, ocean greyhounds, telephony, telegraphic systems, and the thousand and one improvements that contribute to our daily wants, owe their origin not to one, but to many inventors. Some are in advance of the time for the actual demand, others fail, others concentrate all their mental energy on this failure, and master it, to fail in some other point. And so the wheel of time rolls on; new brains with better auxiliary appliances come upon the scene, and at last man is the conqueror, and the result is then merely competitive as to details and efficiencies, the basis of success being attained. The inventors who, if they failed individually, contributed to the grand attainment collectively, their names are recorded in sand. We have reached a stage now in aërial navigation in which engineering skill and forethought can suggest the best structure for lightness and strength, and more especially the materials best suited to the purpose.

Models.—Working models are delusive unless they are made for a practical purpose in a practical manner. Of what use would a model of an automobile omnibus car be if made exactly to scale and about the size of an

automotor tricycle. The true demonstration would be to build the tricycle *as* a tricycle, and suitably equip it as such. Suppose a model was made of a large ocean liner 600 ft. long upon a scale of $\frac{1}{4}$ in. to the foot, say $\frac{1}{48}$th full size, and to demonstrate by that model what could be done upon a larger scale. Here the model would be 12.6 ft. in length, 1.9 ft. midship beam, with a depth of 2 ft. Here the low-pressure cylinder of one of the twin screw engines would be 2.75 in. in diameter, and the high-pressure cylinder 0.87 in., and the boilers and fuel spaces equally useless, although strictly to scale. Would it not be better to consider the model as a launch, engine it as such, and demonstrate it as a successful launch, but not as a sample of what an ocean liner forty-eight times its size should be. As a matter of fact, the ocean liner is far more efficient than a small launch could be.

The waste and leakage incidental to machinery and friction do not increase proportionately to the size and power. Therefore, if an air-ship be made to carry two persons, it should be clearly understood that the calibre and structure are suited to such a load, but a ship to carry one hundred persons would be a specially constructed apparatus, not following the lines of the first with proportionate dimensions. Let the demonstration be regarding the model, if so considered, that two persons can be carried by vertical and horizontal propulsion through the air at a certain speed, and it is fair to suppose that a more efficient apparatus may carry one hundred persons, the whole structure being designed with that object alone.

An automobile car may be correctly defined as a substitute for animal power for drawing loads and passengers. It is, however, obvious to the merest tyro that to adapt the mechanical power derived from the

motor to a set of artificial legs is not to efficiently carry out the required object. Therefore our substitute takes the form of wheels mechanically driven from the axis. A continuous rolling motion is sustained by the motive power, resulting in progression upon the surface of the ground against the resistances of a load and of traction, in contradistinction to the pedaneous movement of animals. No analogy can be instituted between these mechanical functions, except in that the same duties are fulfilled in both cases. Again, the propulsion of a

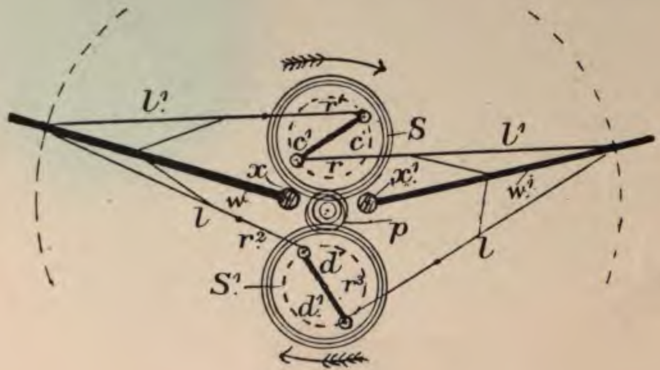

Fig. 73.

ship is in no way analogous to the invisible darting movements of the bonito or the dolphin. We do not intend to assert that wings are not suitable to the mechanical movements derived from motors, but that such a mode of artificial flight must, to be effective, be supplemented by the screw propeller. Some engineers have pronounced against the possible use of wings upon the grounds that the strains and stresses set up by unbalanced forces in the application of sufficient power to effectively act upon the comparatively large surface

would prove immediately destructive to the apparatus. A reference to Fig. 73 shows that the forces need not be unbalanced if the vertical motion is produced and sustained by the wings, partly flapping, and partly as an aëroplane, the horizontal progression depending upon a propeller or propellers.

Let w, w^1 be the wings, jointed at the fulcrums x, x^1, and p a pinion driven directly by the motor, and gearing with two spur wheels S, S^1 of equal diameter. c, c^1 is a pair of opposite cranks on S, and d, d^1 a similar pair on S^1, the latter effecting the downward stroke, and that of S the corresponding upward stroke. The wings are linked to the connecting rods r, r^1, r^2, r^3 by means of plate links l, l^1, and the surfaces are plain or may be valvular, opening upon the up-stroke and closing upon the down-stroke. As a lifting and soaring mechanism this has a greater efficiency per square foot per H.P. than a rotating propeller or set of propellers, yet for horizontal propulsion the latter is without doubt the best mode of utilising power.

Adverting to the subject of sensitive equilibrium, it is obvious that a large air-ship is less sensitive than one of smaller calibre, in the same degree as an eight-oared outrigger is to a yacht. The control is not necessarily anticipatory, it becomes a method of steering, and can be automatically effected by a suitable gyrostat. Also while an aërostat forms part of an air-ship, the equilibrium is more easily maintained.

The aërostat, without departing from the range of foresight incidental to common-sense, will not eventually form any part of the structure of the practical air-ship. The want of confidence in entrusting life and property to suspension in an unstable element by reliance upon the fallibility of mechanism will keep the aërostat for some time until security is assured, and the contempt born of

familiarity prevails. It will not disappear at first, but will be used to render the comparatively heavy structure more buoyant, and so will die away by degrees, unless used for towage, and the flotation of loads.

The steering of an air-ship is an important feature bearing upon its general structure. The steering has not only to be operated from side to side, but also up-

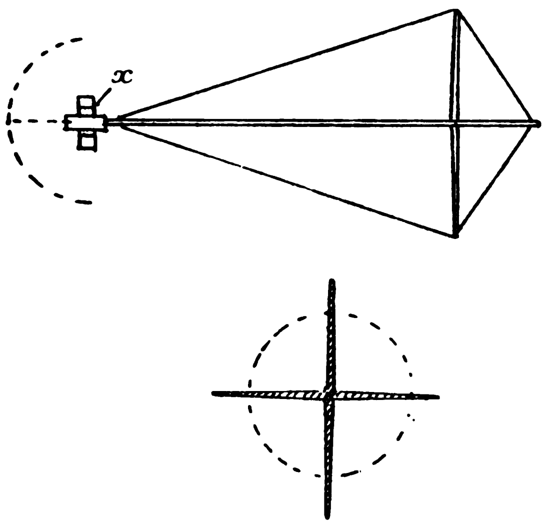

Fig. 74.

wards or downwards. The only effective rudder is shown by Fig. 74 in plan and cross section, x being a gimbal fulcrum, and the dotted outlines the directions of motion.

The area of each plane should be one-third that of the total area of the ship. The steering may be better controlled by small electro-motors operating worms or endless

screws and toothed quadrants, the current being derived from a small dynamo-generator driven from the shaft of one of the propelling motors. A pair of two-way switches may thus constitute the steering board, upon which will also be fixed the aneroid barometer, magnetic shielded compass, thermometer, hygrometer, and clinometer.

Sir Hiram Maxim has adopted such a pair of rudders to one of his recent aëroplanes, Fig. 75, which it may not be out of place to describe fully in connection with the tail vanes or rudders B. The frame is built up of two main side trusses a, a^1, a^2, a^3, a^4, and the framework is also

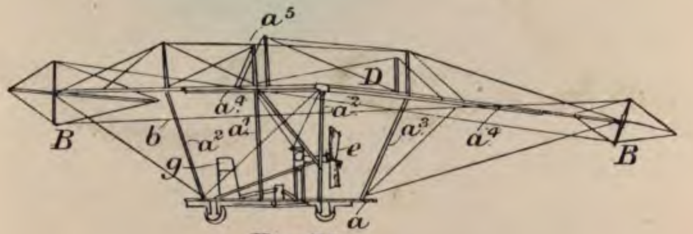

Fig. 75

provided with tubular struts, braces, and guys, and a^1 and a^3 are extended above a^4 so as to allow of the suspension of pivoted auxiliary wings or vanes, as at a^5. Longitudinal stays or wires support the main aëroplane D. Tail vanes or rudders B are pivoted at each end of a^4, and tied together by crossed wires b, and are operated from the platform by cords and winch, or a piston and cylinder. Means are provided for the adjustment of the inclination of the aëroplane. Two screw propellers of light and elastic formation, e, are driven by twin engines operated by pressure derived from a steam generator g of peculiar construction. The

medium is the vapour of gasoline or other easily volatilised fluid, which may be condensed after exhaustion by the exposure of the surface of the tubular framework to the atmosphere, from which it is returned to the generator by the feed pumps. The platform or car is supported by wheels when upon the ground to facilitate the ascent and descent.

Having thus considered as far as possible the general details, we may deal with the structure of any air-ship, taking the suitable materials and application of them in due order.

Framework.—We see, since the adoption by the public of cycles and autocars to such an extent as to create a separate branch of manufacture, that tubular frames have reached the highest point of efficiency, which is the attainment of the maximum of strength with the minimum of weight.

The "modulus of rupture" is eighteen times the load that is required to break a bar 1 in. square cross section, supported at points 1 ft. apart and loaded in the centre, and the following table gives the values in tons per square inch, according to Rankine and Clark's tests:—

Material.	Modulus Tons per Square Inch.
Steel tube	20 to 28
Wrought-iron bar	20 to 21
Riveted tubes, plate iron	13 to 15
Plate beams	18 to 20
Cast-iron bar	13 to 15
Cast-iron tube	11 to 12
Wood—Red pine	3 to 4
Spruce fir	4 to 5
Larch	2 to 4
Saul	7 to 10
Teak	6 to 9

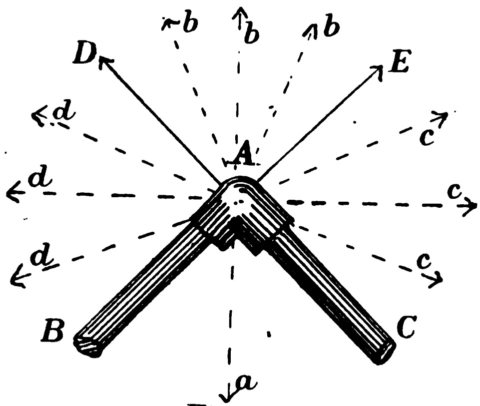

Fig. 76.

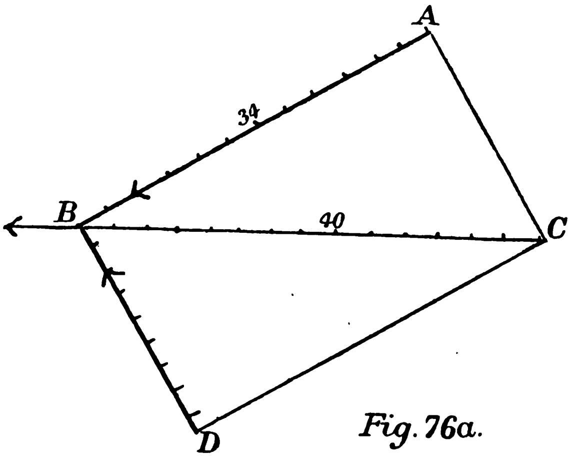

Fig. 76a.

And the corresponding weights of drawn steel tube, suitable for framework, are here tabulated according to pounds per lineal foot per gauge:—

Bore in Inches.	Thickness of Metal in Parts of an Inch.								
	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
$\frac{1}{4}$	.098	.21	.5	.9	1.3	1.9	2.5	3.1	3.9
$\frac{3}{8}$	.118	.3	.7	1.1	1.6	2.3	2.9	3.8	4.6
$\frac{1}{2}$	.178	.4	.83	1.4	2.0	2.7	3.5	4.3	5.3
$\frac{5}{8}$	...	.46	1.1	1.6	2.3	3.1	3.9	4.9	5.9
$\frac{3}{4}$	...	.54	1.2	1.9	2.6	3.5	4.5	5.5	6.6
1	...	.7	1.5	2.4	3.3	4.3	5.5	6.7	7.9
$1\frac{1}{4}$	...	.87	1.8	2.9	3.9	5.2	6.4	7.8	9.3
$1\frac{1}{2}$	...	1.0	2.1	3.3	4.7	5.9	7.4	8.9	10.6
2.0	...	1.4	2.8	4.3	5.9	7.6	9.5	11.3	13.2

In polygonal framing, in order to determine the character of any strain, we will suppose AB and AC (Fig. 76) to be any two bars of a frame. Produce the lines AB, AC, to D and E. Let *a* represent the direction of the load if it passes in any direction between B and C, or *b* if it passes in any direction between D and E, *c* if between E and C, or *d* if between B and D. Then *a* will be in *compression* on AB and on AC, and *b* will be in *tension* on AB and AC, *c* will be in tension on AB and in compression on AC, while *d* is in compression on AB and in tension on AC. The resultant strains may then be computed in numerical value by constructing a parallelogram of forces, as Fig. 76*a*.

Let AB and BD be two forces, strains, or loads, be measured off to any scale according to the known value,

and the direction in which they tend. Join DC and AC parallel to AB, BD. The diagonal BC then represents the resultant, in direction and value when scaled off corresponding with AB, BD.

Castings.—For lightness and strength all joints for framework should be made of one of the aluminium alloys of either of the following grades :*—

Composition per cent.			Strength, Tensile, per sq. in.	Elongation per cent.
Aluminium.	Copper.	Zinc.		
5.8	67.4	26.8	95.712	1
3.3	63.3	33.3	85.867	7.6
3.0	67.0	30.0	67.341	12.5
1.5	77.5	21.0	32.356	41.7
1.5	71.0	27.5	41.952	27.0
1.25	70.0	28.0	35.059	25.0
2.5	70.0	27.5	40.982	28.0
1.0	57.0	42.0	68.218	2.0
1.15	55.8	48.0	69.520	4.0

* A binary aluminium alloy containing 7.5 per cent. of tungsten has recently been put on the market, gives a tensile strength of 15 tons per square inch, the specific gravity being 5.58. A ternary alloy, *Wolframinium*, contains 98 per cent. aluminium, 1 per cent. tungsten, and 1 per cent. copper; specific gravity 2.74, tensile strength wrought 15 tons per square inch, cast in chills 12 tons, rolled or drawn 22 tons. *Romanium* contains 1 per cent. tungsten, 1 per cent. nickel, and the specific gravity is 2.75. It is harder and possesses greater elasticity than the former alloys, and takes tooling better than Hèroult aluminium.

Magnalium.—This is an aluminium-magnesium-antimony alloy, tensile strength 14 tons per square inch, specific gravity 2.52+0.03. It may readily be integrally joined by soldering or semifusion, analogous to welding, and is in great demand in Germany in automobile car frames.

The first composition shows the best result, and its weight per cubic inch is 0.2873 lb. In casting it flows well, and gives a sharp clean casting, and is best made by adding the aluminium to the copper after the zinc has thoroughly melted and combined with it.

Aluminium solders may be made by melting 20 parts of aluminium and adding 80 parts of zinc, and when both are mingled add some Russian tallow, stir with an iron rod before casting into sticks. The flux is 3 parts copaiba balsam, 1 part Venice turpentine, and half a teaspoonful of lemon juice.

For blow-pipe soldering the following is the best composition :—

Aluminium - - - -	20 parts
Copper - - - - -	10 „
Tin - - - - -	60 „
Silver - - - - -	10 „
Zinc - - - - -	30 „

Bearings.—The most important bearings are the thrust bearings of the propeller shaft. These should be made so as to run in an oil bath, and have thin radiator plates cast around it to dissipate the heat generated by friction. If the thrust be upwards, as in vertical propulsion, the outer shell of the jacketed casting should be cast with lugs on it to which may be attached the carrying stays, strong spiral springs being interposed to prevent excessive vibration, and to neutralise shocks. A guard plate with a collar on the shaft should be added above the thrust bearing, with separate stays to prevent accidents if the thrust should give way. The pressure on the thrust bearings may be estimated at 60 lbs. per square inch.

The external diameter of the collars should be as D+D 0.23, and the number of collars proportioned directly to the load W in pounds, A being the total bearing contact area of the collars.

$$A = \frac{W}{60} \text{ and } \frac{A}{n} = \text{area of}$$

one collar, n being the number.

The ordinary high-speed engine bearings have a pressure of 200 lbs. per square inch, and the length should be D 4.3 to D 6 for shafts from 2 to $1\frac{1}{4}$ in. diameter, and D 3 as a standard from 3 in. diameter upwards.

Shafting.—The diameter of mild steel shafting in inches is calculated from

$$D = 5 \sqrt[3]{\frac{HP}{V}} \text{ where } V =$$

revolutions per minute. This formula shows that the greater the velocity, the less torsional strain is imposed, and hollow shafts resist torsion better than solid ones of the same area. The weight w in pounds per lineal foot is

$$w = D^2 \times 2.647$$

and for hollow shafts the lesser diameter is deducted—

$$w = D^2 \times 2.647 - d^2 \times 2.647.$$

The distance between bearings where no work is taken off the shaft, b being in feet—

$$b = 5 \sqrt[3]{D^2} \text{ (D in inches).}$$

Wire Stays.—Wire rope and single strand stays are best made of Delta metal, No. 1 alloy, since by the following comparison the tenacity is good according to

test, and since a smaller diameter may be used to resist a greater strain than is the case with iron or steel wire, with the further advantage of being non-corrosive under atmospheric changes, it may be used for aëroplane, wing, and rudder rigging.

A comparative table gives the tenacity in tons per square inch :—

Metal.	Tenacity in Tons per Square Inch.
Delta metal, No. 1	48
Delta metal, No. 2	41
Manganese steel	38
Nickel steel	34
Aluminium, 1 per cent. bronze	35

The weight of Delta metal is 0.3236 lb. per cubic inch, therefore the weight is

$$\mathrm{D}^2 \times 9.24 \times 0.3236 = w \text{ in pounds.}$$

Wood.—In the construction of air-ships a certain quantity and quality of wood must be used, and there are various kinds suitable for special purposes, among which we may instance :—

Ash, for elasticity, but not good for weather alternations. American varieties are best.

Beech.—The white variety admits of thin division.

Wych Elm.—Especially suitable for steam bending.

Rock Elm (*American*).—Closer grain, and better to work.

Oak.—Durable in exposure to weather; light, hard grain, but works well. On account of the tannin contained, it must not be used in contact with iron.

Plane (*Sycamore*).—Works well, very durable.

Willow.—Suitable for friction pieces—brake blocks, sheaves, &c.; the weight per cubic foot being given in order to facilitate calculation.

Wood.	Specific Gravity.	Pounds per Cubic Foot.
Ash - - - - - -	800	50
Beech - - - - - -	690	43.12
Wych elm - - - - -	570	35.62
Rock elm - - - - -	671	41.93
Oak - - - - - -	872	54.5
Plane - - - - - -	623	38.93
Willow - - - - -	486	30.37

Aeroplanes and Aerocurves.—When these are made of fabric, yacht duck may be employed if a broad mesh about 8 in. pitch of No. 18 S.W.G. Delta metal wire is used on the back surface against the pressure. The ends of the mesh should be twisted and soldered around the bolt ropes or wires forming the hemmed edges. The weight of a square foot of undressed duck canvas is .0512 lb., and fine sail canvas is .0678 lb. per square foot; pegamoid, .1032 lb. per square foot; sylamoid (deteriorates rapidly when subjected to heat), .0785 lb. per square foot. For gas envelopes undressed Tussore silk weighs .0175 lb. per square foot, dressed .048 lb. Urtalaine, a fabric made of Rhea fibre, similar to silk, but weight for weight of less tenacity, .03986 lb. per square foot dressed. Calico, dressed, .0598 lb. per square foot.

If sheet metal, such as aluminium, be used, the

following table gives the weight per square foot in pounds, relatively to the gauge:—

B.W.G.	Thickness, Inches.	Pounds per Square Foot.	B.W.G.	Thickness, Inches.	Pounds per Square Foot.
28	.015	.20	22	.029	.39
27	.018	.24	20	.035	.47
26	.020	.27	18	.048	.68
25	.021	.28	16	$\frac{1}{16}$	.83
24	.025	.33	14	.080	1.07
23	.028	.34	12	.109	1.49

From the data given as to suitable materials, strength and weight, with a reasonable design in view which may be practically applied, an air-ship may be constructed, always bearing in mind that the dimensions requisite in order to successfully carry 1 ton are not to be considered as a unit that has but to be doubled in every particular in order to carry 2 tons, and the same reservation equally applies to velocities. And hitherto we have presumed a still atmosphere, but the structure should be designed and proportioned to withstand the strains and stresses imposed by a gale of wind, plus the contained power to sustain a reasonable speed under the circumstances.

This points at once to the greater efficiency to be attained by air-ships of greater calibre, relatively to the best work of the one or two passenger air-yachts.

CHAPTER VIII.

AIR-SHIPS.

IN this chapter we propose to treat of air-ships as combinations of aërostat, aëroplane, and propelling apparatus, dealing with all the best experimental types categorically without reference to the merits of each.

It is, however, worthy of remark, that Mr J. M. Partridge in 1847 invented and made an air-ship which

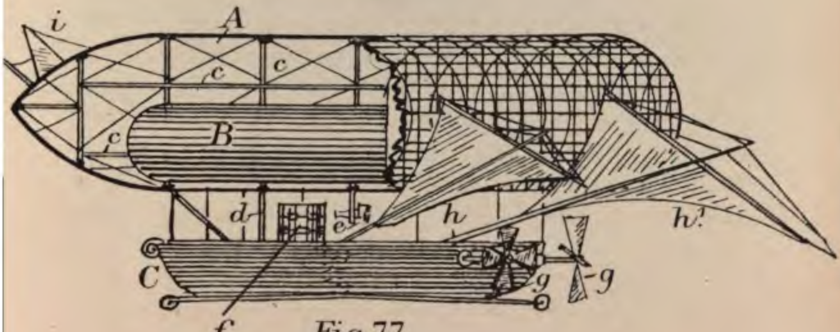

Fig. 77.

he termed "Pneumadrome," and made several successful flights, the steering, however, being imperfect. Many valuable points of his invention have lain dormant for fifty-five years, to be resuscitated as chief and prominent features in our latest practical development of aërial navigation. Partridge, however, had neither oil engines, aluminium, nor pure hydrogen available in his day. This air-ship is shown by Fig. 77.

The aërostat A is formed upon a light frame consisting of rings, held together by longitudinal bars *c*, and trussed to equalise the strain. The fabric was drill canvas, treated with caoutchouc in solution, and weighed 1 lb. per square yard. An internal air-bag or envelope B was controlled by a valve and pump *e* in connection with the generator *f*. A head sail *i* and stern sails *h*, *h'* had braces and halliards for steering. The car C contains the motors, and the apparatus was driven by three propellers *g*, of which only two are visible. The body of the aërostat was covered by a light wire netting, in addition to that carrying the car, and the sails *h*, *h'* acted as aëroplanes as well as for steering purposes. The air-chamber B fully compensated the variations of gas volume and pressure in A, and this, with other parts of the structure, have been utilised in later machines.

Folacci and Bertius' air-ship is shown by Fig. 78, in which the aërostat *a* is provided with a deep under-hung keel *d* in which horizontal propelling screws *e* revolve in casings. A rudder *m* has a cased propeller A, and a tail rudder *i* has another cased fan *h*, and both rudders may be moved laterally to effect horizontal steering. The mechanism is driven by a motor in the car *g*.

Fig. 79 illustrates Falconnet's air-ship, in which two hollow cones A, A abut against an intervening cylinder B, the whole constructed on one frame of steel tubing, strengthened and stayed by double braced trussing *c'*, *d'*, ties *g*, and stanchions *e*. The shell of the aërostat is made of very thin metal, or fabric rendered impervious to gas and water, and is divided by partitions into subsections *a*, having manholes, gas supply, and exhaust pipes with stopcocks arranged for filling or exhausting any of the chambers independently. The double trussing *d'* forms the roof of, and supports the engine-room and cabin *k*, which is partly within and partly extends

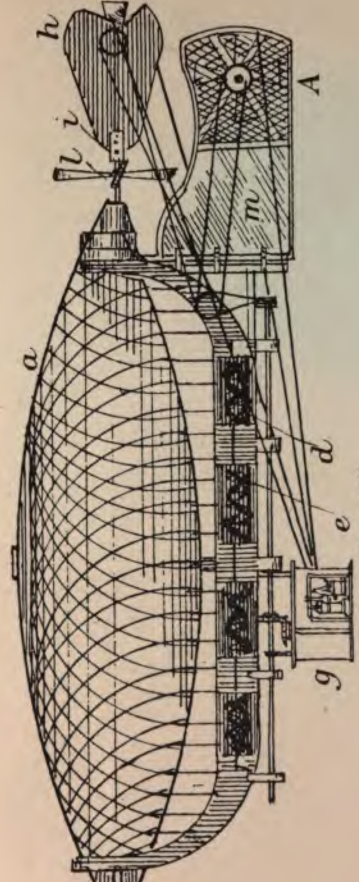

Fig 78

Fig: 79.

below the structure of the air-ship. A chimney *s* is provided to carry off the products of combustion and foul air from a vertical uptake *t*. The cabin is formed with sharp ends to reduce resistance, and also has suitable doors and windows. Horizontal longitudinal shafts carry propellers *n*, with an after propeller *m* which may be moved by universal joints in any direction for steering, and effecting horizontal or vertical deviations in the direction of flight, the brackets *l* being properly constructed for this purpose, the dotted outline *h* showing such deviation.

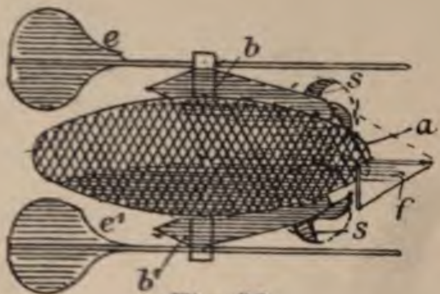

Fig. 80.

The Hilfreich air-ship (Fig. 80) is shown in plan, and the aërostat *a* is elliptical in shape, and supports two cars *b*, *b′* connected by a transverse gangway (not shown). It is propelled by two feathering paddles *e*, *e′* which afford the horizontal propulsion, and two screw propellers *s*, *s′* effect the vertical movement. Steering is performed by a movable vane or fin *f*, and the mechanism is driven by an internal combustion engine.

Molesworth-Hepworth's air-ship is shown by Fig. 81, in which the aërostat A, having pointed ends B, is divided into compartments by divisions C in which are separate gas-bags D, with independent inflating and deflating

appliances. A longitudinal bar E supports an aëroplane H, itself being supported by rigging C from the aërostat A. The car I is supported by and below the bar E, and forms the centre of buoyancy of the air-ship, the supporting bars K being rigid, except for horizontal angular deviation by means of the ropes M, by means of a quadrant or bell crank lever N or a windlass. One or more propellers O are driven by the motor through

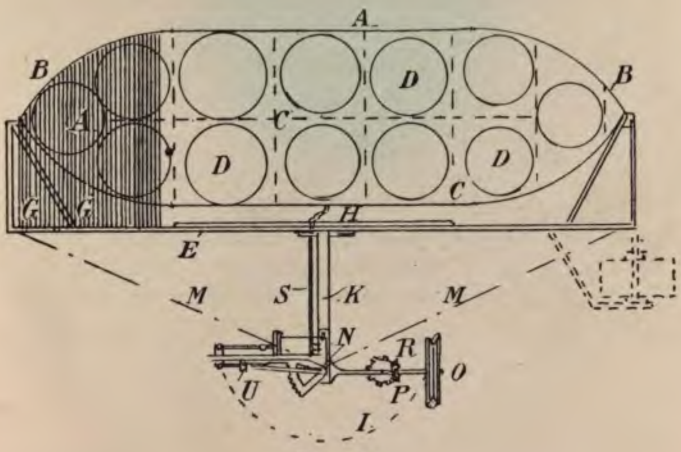

Fig. 81.

gearing R, these propellers having stiff leading edges and elastic or flexible rear ones. The buoyancy of the aërostat A is controlled by varying the pressure of air in the intervening spaces between the gas-bags D by means of a pump U, and flexible pipe S, with a suitable liberating valve. A rudder is shown in dotted outline.

De Bausset's air-ship is shown with the aërostat in section by Fig. 82. The aërostat A is built up of steel or thin metal plates, with internal bands and cross ties to

strengthen the structure. Conical ends O are provided which are normally held in position by the external atmospheric pressure, since the inside of A is partially exhausted, spiral springs in tension tending to open

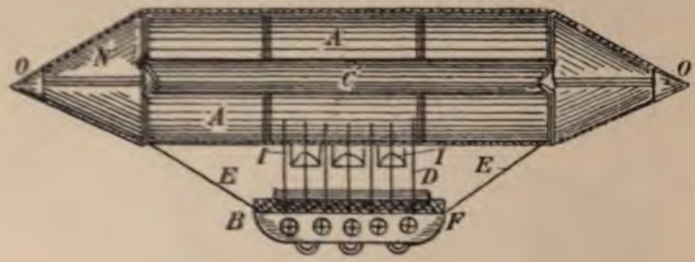

Fig. 82.

O if the internal pressure increases. Central sustaining planes or steadying plates C are fixed centrally within the aërostat A. The boat-shaped car B is adapted for floating upon the water, or for land transport upon the wheels, and is suspended by means of jointed rods D,

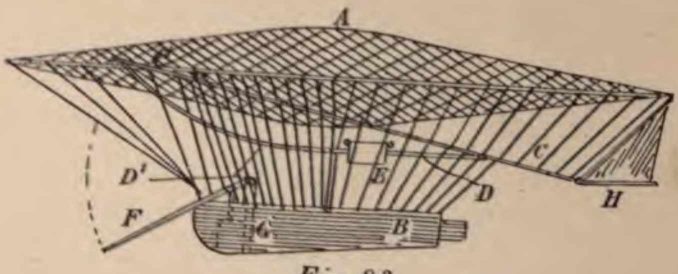

Fig. 83

and a rope E upon a windlass allows of its being adjusted forwards and backwards. Boxed or cased propellers I provide the necessary propelling force, and these are independently driven by the current derived from

accumulators in the car B. The altitude is varied by admitting air to or exhausting the interior of the aërostat A, a suitable electrically driven pump performing this operation.

Fig. 83 represents Worm's air-ship. The aërostat A is nearly buoyant enough to support the whole mass, and has attached to each side inclined aëroplanes, the edge C of which only is visible upon the elevation. A curved rod D extends from one end to the other of the

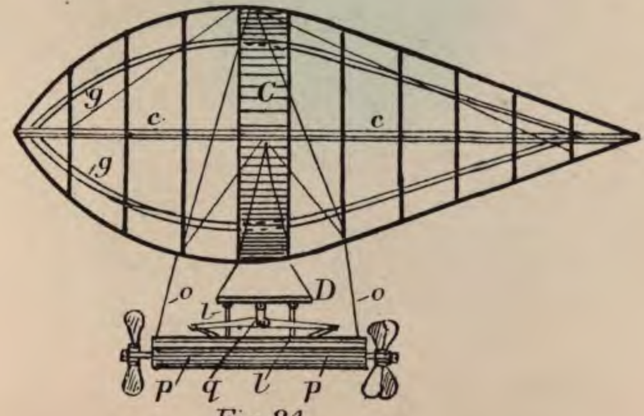

Fig. 84.

machine, which carries a balance weight E. H is a tail-piece or rudder, capable of being moved upon a vertical axis. Propulsion is effected by means of feathering wings F, to which motion is imparted by an internal combustion or other motor D′. By adjusting the balance weight E upon the rod D, the aëroplane C and the whole machine may be made to assume an inclined position, so that the combined action of the wings F and aëroplane C tend to raise the air-ship and propel it forwards. The car B is of wedge shape in plan, and carries the generator,

storage tank, or the like, G, and the motor D′ with the fulcrums of the wings F.

Boisset's air-ship is illustrated by Fig. 84, and consists of an aërostat, the frame of which is formed of a number of light metal or bamboo rings with radial struts threaded upon an axial tube *c*. Transverse stays *g* tie the ends of *c* to the upper periphery of the central ring of the frame, and the whole is covered by a double layer of silk cemented together by indiarubber solution. The car *r* is suspended from a plate D secured to a band C round the largest circumference of the aërostat and

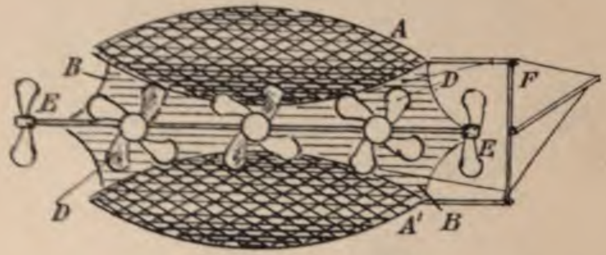

Fig. 85

steadied by ropes *o*. The actual suspension is effected by link work *l*, *q*, which tends to keep the car in position when the weights therein are shifted. Propulsion is effected by a single screw propeller in front of the car, and twin propellers at the rear end, the steering being performed by the manipulation of the latter.

An air-ship with twin aërostats has been invented by L. E. Roze, and shown by Fig. 85, which is a plan view. The two aërostats A, A′ support the car B, and are so connected that the internal pressure is equal in both, and a collapsible reservoir is provided in order that the gas may expand without loss. Propulsion is effected by two

horizontal propellers E, and vertically by three similar propellers the axes of which are at right angles to the horizontal plane. The air-ship is steered by a tail-piece or rudder F. The framing of the car B is provided with buffers or check springs to neutralise shocks when coming to rest.

Fig. 86 is an end sectional view of Chillingworth's air-ship, which consists of an aërostat D supporting a car *v*, and propelled by feathering wings B, formed of an elastic framework covered by textile material, the dotted

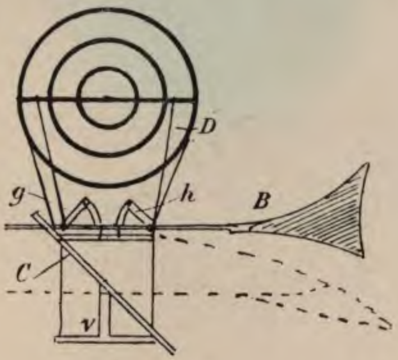

Fig. 86.

outline showing the position assumed when at rest. The inner ends of the wing arms carry toothed segments which gear with each other, shown by *g*, *h*, which are worked by a reciprocating motor, the feathering being actuated by stop links. A rudder attached to the car C admits of steering in any direction. The aërostat is divided into three or more internal chambers, the inner of which may be inflated or deflated with air to compensate the variation of the volume of gas in the outer envelopes.

Middleton's air-ship, an elevation of which is shown by Fig. 87, also consists of two parallel aërostats *b*, *b'* similar to that of Rose, previously described. The aërostats *b*, *b'* are drawn together by a bent longitudinal frame *i* to which is attached a curved shield plate, which effectually screens the aërostats from the heat radiating from the motors and generator *g*. Internal bags or envelopes, shown by the dotted lines *c*, *c'* within the

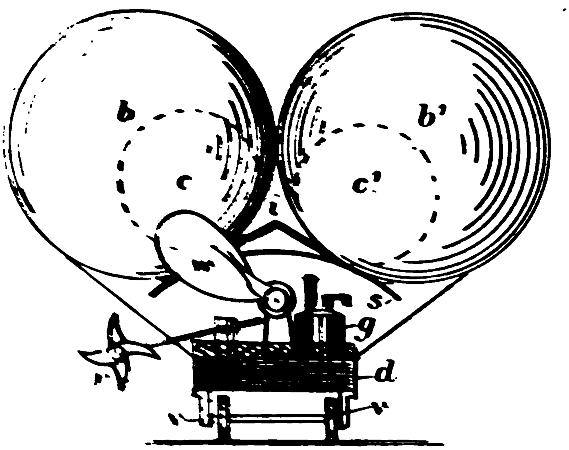

Fig 87.

aërostats *b*, *b'*, are provided to act as partial condenser for the exhaust from the motor, the heat thus dissipated expanding the volume of the surrounding gas. Propulsion and steering are effected by a propeller *w* and an auxiliary propeller *r*, the rotation being performed by the motor and the variation of the planes by hand in both cases.

Fig. 88 is an elevation of Pennington's air-ship, which consists of an aërostat A of sheet aluminium carrying at

its bow a propeller F driven by a motor M placed within a recess in the aërostat, accessible from outside. Central aëroplanes E are attached to each side of the aërostat A,

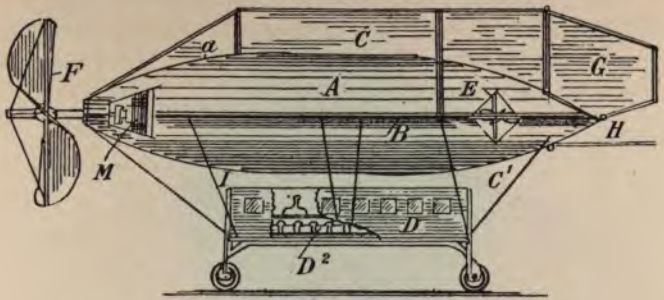

Fig. 88.

and lifting propellers E are fixed to revolve within suitable frames in these aëroplanes. A fin or central vertical plane C is attached to the top of the aërostat. The car

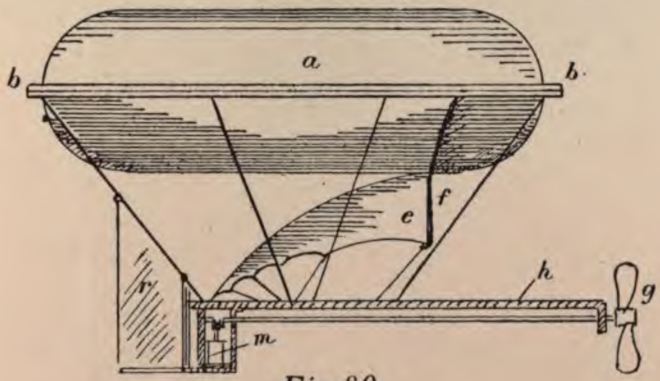

Fig. 89.

D is divided into two compartments, one above the other, the upper one being for passengers and auxiliary appliances, and the lower D^2 for electrical accumulators which

supply the current to electro-motors driving the lifting fans E and the vertical and horizontal rudders G, H, also the ignition for the explosion in the cylinders of the vapour engine M. The liquid hydrocarbon is stored under pressure, and the framework and all parts are hollow, and filled with gas. Stays C′ maintain the rigid position of the car D.

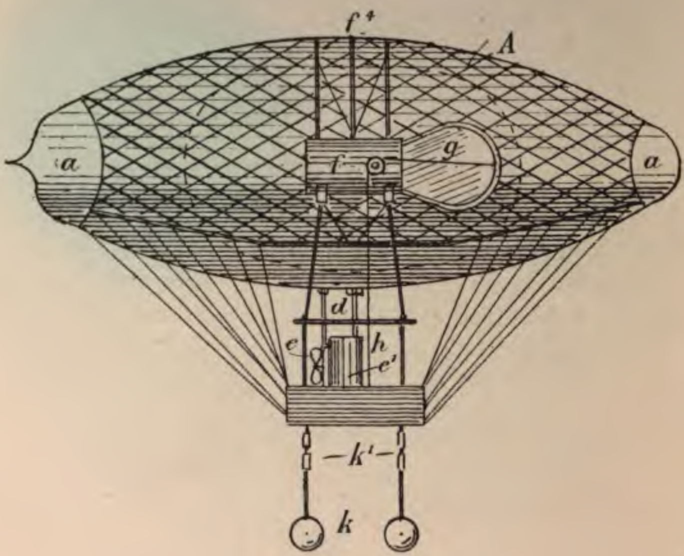

Fig. 90.

Lochner's air-ship is illustrated by Fig. 89, and has an aërostat *a*, with a central aëroplane *bb* surrounding it, and a curved adjustable aëroplane *e* below it, this having a rigid weather edge *f* which is carried upward to the central aëroplane *bb*. The reaction of the air currents escaping from the rear lower edge of *e* tends to an impulse forwards. The aërostat *a* may be circular in plan,

and the lower portion may, by collapsing into *bb*, act as a parachute. A narrow horizontal beam *h* carries the propeller *g* and its shaft and bearings, a small car containing the motor *m*, and steering gear for controlling the rudder *r*.

Hite's air-ship, shown by Fig. 90, consists of an aërostat A, with metal end caps *a*, and has an internal air-bag, as shown by the dotted outline, which is inflated

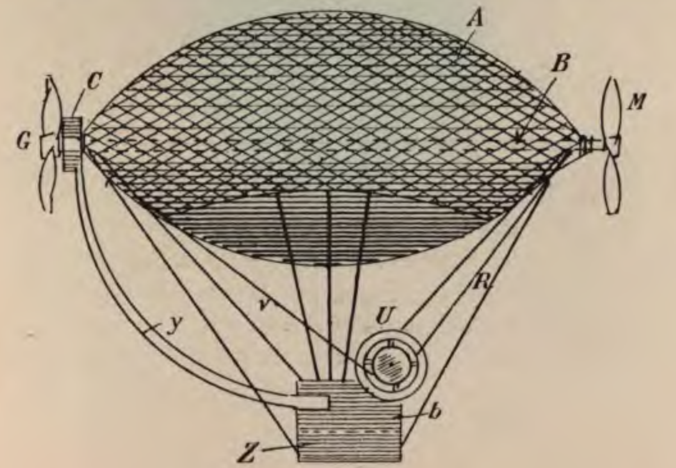

Fig. 91.

or deflated according to the pressure of gas in the aërostat. The gas envelope of the aërostat A is connected to a heated elastic vessel *e′* through a pipe *d*, and is kept in circulation by a fan *e′*. Cased propellers *f* are attached to the machine by saddle frames f^4, and to each is hinged a rudder *g* which is operated from the car by ropes and pulleys. Ballast chambers *k* are suspended from the car by cords or links *k′*.

Fig. 91 illustrates Blümelhuber's air-ship, consisting

of an aërostat A, with a central horizontal tube B of metal, shown by dotted lines, through which a shaft passes, carrying two propellers G, M, driven by an electro-motor C which is supported by the thrust bearings of

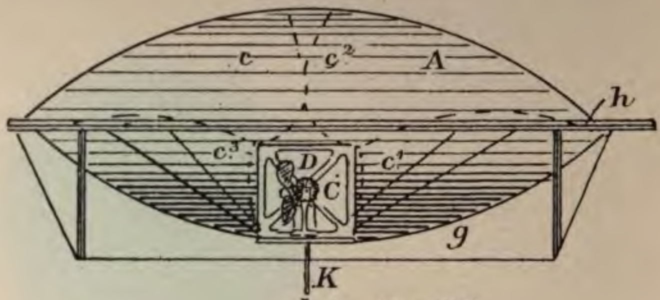

Fig. 92.

the shaft B and a curved bracket *y* upon the car. The steering is effected by mounting the propeller M upon a universal joint, so that its plane of rotation may be inclined. Electrical accumulators are provided in the lower

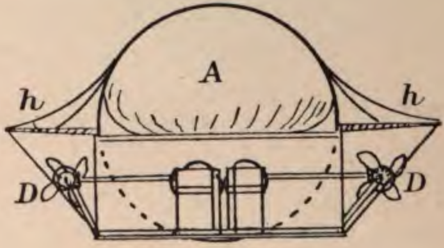

Fig 93

partition *z* of the car, to furnish the driving power for the motor C.

Nahl's air-ship is shown in elevation by Fig. 92, and a midship section Fig. 93. The aërostat A is internally

divided by gas envelopes c, c^1, c^2, c^3, and the car C is fixed to the framework of the outer casing of the aërostat and is actually inside it, below the central surrounding aëroplane *h*.

An electro-motor drives two propellers D, D, effecting horizontal propulsion, and a weight J supported by a rod K admits of the adjustment of the centre of buoyancy, and also for ballast.

Professor Langley, of the Smithsonian Institute, U.S.A., has constructed an air-ship (Fig. 94) in which

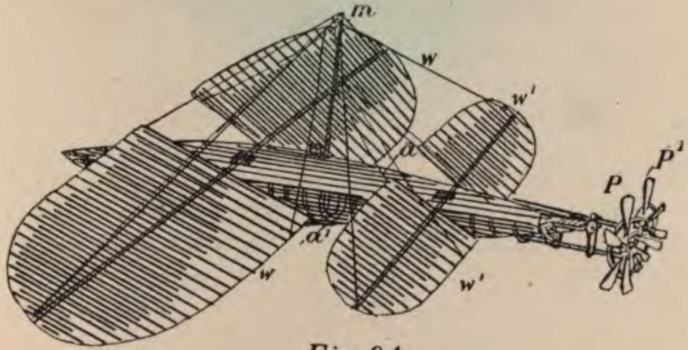

Fig. 94.

the upper part of the body *a* is an aërostat, and the lower part *a'* an open framework carrying the motors operating the horizontal twin propellers P, P', steering being effected by varying the rates of rotation of these independently of each other. Aëroplanes *w*, *w'* maintain by their angle of inclination the vertical lift, and are supported by and controlled from a mast *m*.

Count von Zeppelin's air-ship is shown in elevation by Fig. 95 and midship section by Fig. 96. The aërostat comprises a framework of longitudinal tubes *r* interspaced by wire ropes *s* proceeding radially from central

hubs *w*, a vertical strut *v* being placed at intervals across the diameter of the aërostat throughout its length. It is divided into compartments containing gas-bags shown

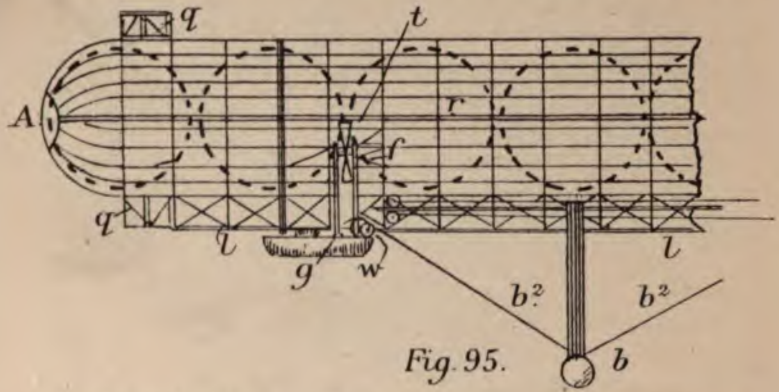

Fig. 95.

by the dotted lines. The aërostat is very long relatively to its diameter, and supports two boat-cars *g*, one only of which is shown. A gangway *l* runs the whole length

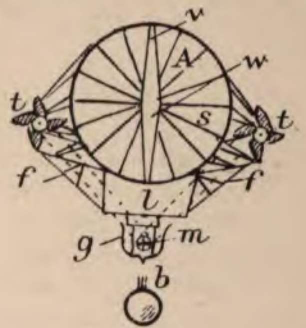

Fig 96

of the machine from which any part may be reached by ladders *f*. Several aërostats may be joined together forming a flexible train propelled by the air-ship, and

carrying goods or passengers. The junctions are coupled by universal joints and the fabric of the aërostats joined by strips of similar fabric.

Horizontal steering is effected by rudders q, q', and the inclination of the axis is adjusted by means of a weight b suspended from a wire rope along which it is made to travel by an endless rope b^2 operated by a winch w' in each car g. The internal combustion engine m is contained in the car g, and drives the propellers t for horizontal propulsion by suitable shafts and gearing within the framework and ladder f.

Santos Dumont has successfully accomplished the steering of an aërostat, notably in open competition in which he was the winner of 15,000 francs by rounding the Eiffel Tower. Since this the inventor has made several successful steering flights. The air-ship consists of an aërostat inflated with hydrogen, and containing an air-bag for compensation, and a screw propeller, the axis of which is inclined, and a rudder of relatively large area is under the control of the aëronaut, who is placed in a small shielded car which also carries the motor engine, preferably an internal combustion liquid hydrocarbon type. M. Dumont has invented a very light and powerful twin or multi-cylinder engine for the purpose, each pair of cylinders being placed in tandem, operating one piston rod, the explosions having the effect of a double-acting single-cylinder engine.

Dr Barton in the United States has just built an air-ship, the trial of which has not as yet been reported. The aërostat has three aëroplanes placed below the centre with an aggregate area of 1,944 sq. ft., which he claims to have a lifting power of 972 lbs. or 1 lb. to 2 sq. ft., equivalent to an air velocity of 880 ft. per minute. There are eighteen propellers arranged at different angles. The aërostat has an internal compensator or

air vessel capable of being inflated or deflated. It is noteworthy that nearly every modern type of air-ship adopts this compensator, and it is invariably referred to as a special feature, although employed, as we have seen, by Partridge in his air-ship the "Pneumodrome" in 1849. Dr Barton renders his air-ship stable longitudinally by forward and rear water tanks, the water of which is kept in constant circulation through a double tubular system by an electrically driven pump. A valve is fitted in each section, these being controlled automati-

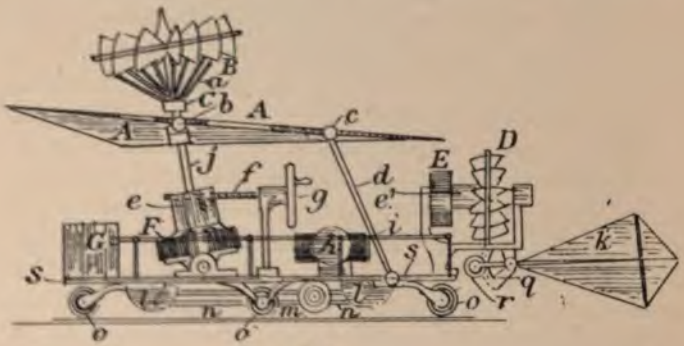

Fig. 97.

cally by a heavy pendulum, one of the tanks being filled and the opposite one emptied inversely according to the tendency of the inclination.

The "Aëraonic" air-ship is as yet the most successful experimental apparatus yet tried, and lengthy trials have been made of a 10 ft. model in which the air-ship was held captive at a height of 100 ft. by a hawser, around which it was steered from the ground by two double pole link switches, the conductors being attached to the hawser and included in the circuits of the steering motor. The electrical current for this and the propelling motors was

generated by a dynamo upon the shaft of a $4\frac{1}{2}$ H.P. petrol twin cylinder motor upon the platform of the ship, and vertical ascent was accomplished without extraneous aid. These successful trials led to the formation of a syndicate, and an air-ship 50 ft. in length and 40 H.P. is now in process of building. Fig. 97 is an elevation of this air-ship, in which a platform *s* carries the whole of the mechanism, and when at rest is supported upon the ground by wheels *o*. A lifting propeller B has a collar C upon the shaft normally held back by the tension of a spring to keep the rear edges of the blades in full pitch position by means of rods *a*. The shaft *j* and electro-motor F which drives it are based upon a pivoted plate upon the platform *s*, the oil-bath thrust block *e* intervening between the motor F and the propeller B, the whole being inclined backwards or forwards by a screw *f* and hand wheel *g*. The aëroplane A is inclined at the same time, being carried by a trunnion bearing *b* on the shaft *j*. Links *d* connect the aëroplane A with the platform *s* and carry the rear weight, being pivoted to A at *c*. The length of the links *d* is such as to bring the aëroplane A parallel with the platform *s* when moved rearward by *g*. The horizontal propeller D is driven by an electro-motor E, and a thrust block *e′* is mounted upon the same bracket. Steering is effected by a four-vaned rudder *k* operated vertically by a toothed quadrant *q*, and horizontally by a similar quadrant, small electro-motors *r*, controlled by the aëronaut by means of switches, furnishing the requisite power. The current is derived from a dynamo electric generator *i* driven directly by a compound internal combustion hydrocarbon engine *h*. The liquid fuel is stored in a wedge-shaped tank G, the apex forming the beak of the platform. Two tanks containing water *l*, *l′*, and connected by pipes and an electrically driven centrifugal pump *m*, are placed on

each side of the under part of the platform *s*, so that the two forward tanks are connected to the after tanks by the corresponding pipes, forming the "fore and rear" equilibrium system, and either the two right-hand tanks or the two left-hand tanks the "lateral" equilibrium system. Therefore since a current of fluid is maintained, a flux to the two forward tanks causes a dip forwards and *vice versa*, or a flux to the two right-hand tanks causes a lateral dip in that direction; and this is automatically effected by two pivoted hollow beams slightly bellied in the centre and partially filled with mercury, and these being arranged at right angles to each other, are connected to the controlling valves of the two fluid circulating systems. The sensitiveness of the mercury balance renders the equilibrium control nearly anticipatory.

No human mind can foresee the air-ship of the future, except that aërial navigation will be a matter of everyday usage, and will give rise to a new industry throughout the world. Unless some future discovery renders the control of the force of gravitation possible by other than mechanical means, the germ of the air-ship is among the many that are described in these pages, doubtless with many modifications and additional details that may be found necessary to accomplish perfect success.

APPENDIX.

TRIGONOMETRICAL EQUIVALENTS.

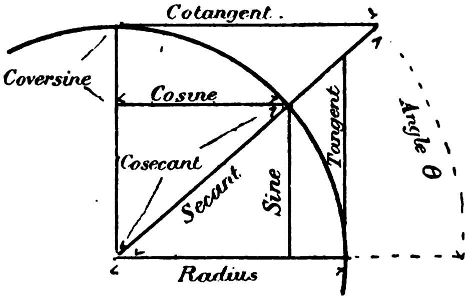

Fig. 98.

THE diagram shows the trigonometrical functions in terms of the angle θ to the radius, the value of which is given as $= 1$.

$$\text{Cos} = \ldots \sqrt{(1 - \sin^2)} = \text{cosine.}$$

$$\text{Cos} = \ldots \frac{\sin}{\tan} = \text{cosine.}$$

$$\text{Cos} = \ldots \sin \times \cot = \text{cosine.}$$

$$\text{Tan} = \ldots \frac{\sin}{\cos} = \text{tangent.}$$

$$\text{Cot} = \ldots\ \frac{\cos}{\sin} = \text{cotangent.}$$

$$\text{Sin} = \ldots\ \frac{\cos}{\cot} = \text{sine.}$$

$$\text{Sec} = \ldots\ \frac{\tan}{\sin} = \text{secant.}$$

$$\text{Sin} = \ldots\ \frac{\tan}{\sec} = \text{sine.}$$

$$\text{Radius} = \ldots\ \tan \times \cot = \text{radius.}$$

$$\text{Sin} = \sqrt{(1 - \cos^2)} = \text{sine.}$$

$$\text{Tan} = \ldots\ \frac{1}{\cot} = \text{tangent.}$$

$$\text{Cosec} = \ldots\ \frac{1}{\sin} = \text{cosecant.}$$

$$\text{Sec} = \ldots\ \frac{1}{\cos} = \text{secant.}$$

$$\text{Sin} = \ldots\ \frac{1}{\text{cosec}} = \text{sine.}$$

$$\text{Cos} = \ldots\ \frac{1}{\sec} = \text{cosine.}$$

$$\text{Cot} = \frac{1}{\cot} = \text{cotangent.}$$

$$\text{Versin} = 1 - \cos = \text{versed sine.}$$

$$\text{Coversin} = 1 - \sin = \text{coversed sine.}$$

Form of Aerostat Ends, Plotting Templets (Fig. 99).—Let AC = D × 1.25, and AB = D. Then from

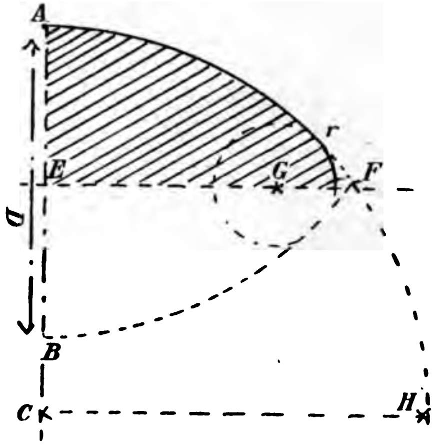

Fig. 99

centre C strike off AE, and upon EF mark off G, that GF = CB, and strike the semicircle radius G*r* cutting AF at *r*. This forms an approximate parabolic outline.

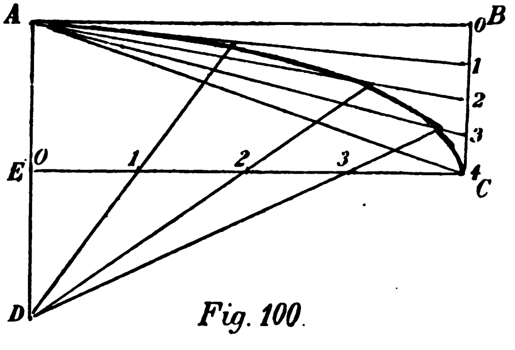

Fig. 100.

To describe an ellipse for an end templet, set off the major axis EC, and mark it off in equal parts, which in

Fig. 99 are four. Let AD = the minor axis, and CB the half of this, which should be divided into an equal number of corresponding parts to EC. From the centre A draw lines cutting divisions on BC, and from the centre D draw lines cutting the divisions on EC. Where the lines intersect are the points cut by the semi-ellipse.

Correction Table of Altitudes and Latitude.

Apparent Altitudes, Feet.	Latitude. + from 0° to 45°; − from 45° to 90°.					
	0° / 90°	10° / 80°	20° / 70°	30° / 60°	40° / 50°	45°
1,000	2.6	2.5	2.0	1.3	·5	No correction for 45°.
2,000	5.3	5.0	4.1	2.6	·9	
3,000	7.9	7.5	6.1	4.0	1.4	
4,000	10.6	10.0	8.1	5.3	1.8	
5,000	13.2	12.4	10.1	6.6	2.3	
6,000	15.9	14.9	12.2	7.9	2.8	
7,000	18.5	17.4	14.2	9.3	3.2	
8,000	21.2	19.9	16.2	10.6	3.7	
9,000	23.8	22.4	18.3	11.9	4.1	
10,000	26.5	24.9	20.3	13.2	4.6	
11,000	29.1	27.4	22.3	14.6	5.1	
12,000	31.8	29.9	24.4	15.9	5.5	

USEFUL CONSTANTS AND LOGARITHMS.

	Number.	Logarithms.
π	3.1416	.4971
π^2	9.8696	.9943
$\sqrt{\pi}$	1.7724	.2486
$\frac{\pi}{4}$	.7854	.8951
Centimetres in 1 in.	2.54	.4048
Yards in 1 metre	1.0936	.0388
Kilometres in 1 mile	1.6093	.2066
Miles in 1 knot	1.1528	.0618
Square mils per square millimetre	1550	3.1904
Cubic centimetres in 1 cub. in.	16.386	1.2145
Cubic centimetres in 1 pint	567.93	2.7543
Cubic inches in 1 pint	34.659	1.5398
Pints in 1 litre	1.7608	.2457
Grains in 1 gram	15.432	1.1883
Pounds avoirdupois in 1 kilogram	2.2046	.3433
Pounds in 1 cub. ft. of water (39° Fahr.)	62.425	1.7953
Forces de cheval in 1 horse-power (33,000 foot pounds)	1.01385	.0058
Foot pounds in 1 B.T.U.	775.47	2.8895
B.T.U. in 1 calorie	3.968	.5986
Degrees Fahrenheit in 1° Cent.	1.8	.2553
Feet per second in 1 mile per hour	1.4666	.1664
Metres per second in 1 kilometre per hour	2.7777	.4437
Pressure pounds per square inch of 1 ft. of water (39° Fahr.)	.4333	1.6368
Pressure pounds per square inch of 1 in. of mercury	.4907	1.6368
Value of g at Greenwich in inch seconds	386.29	2.5869
Length of seconds pendulum at Greenwich, inches	39.139	1.5926

TABLE OF PROLATE SPHEROIDS.

Semi-major axis $= a$. Semi-minor axis $= b$. Volume $= \frac{4}{3}\pi a^2 b$.

Weight Raised, Lbs. (Avoir.) w.	Cubic Feet of Gas (any shape), $h = \frac{w}{.0684}$	Linear Feet Radius, $b = \sqrt[3]{\frac{h}{2.929}}$	Linear Feet Diameter, $d = 2b$.	Square Feet Area $= \pi b^2$.	Linear Feet Length, $l = 12b$.	Square Feet Surface Area, $f = 60.008b^2$.
1	14.60	.834	1.669	2.19	10.013	41.78
10	146.0	1.798	3.595	10.17	21.573	194.00
100	1460.0	3.873	7.746	47.12	46.478	899.64
150	2192.0	4.435	8.870	61.79	53.220	1180.30
200	2920.00	4.879	9.759	74.81	58.557	1429.70
250	3655.0	5.259	10.518	86.89	63.109	1659.60
340	5000.0	5.838	11.676	107.08	70.058	2021.80
440	6000.0	6.203	12.407	120.91	74.446	2317.60
500	7310.0	6.626	13.252	137.93	79.512	2634.60
547	8000.0	6.828	13.656	146.48	81.939	2784.10
650	9000.0	7.101	14.203	158.44	85.220	3026.70
684	10000.0	7.355	14.711	169.97	88.226	3247.10
750	11000.0	7.593	15.186	181.12	91.116	3459.60
800	11695.0	7.749	15.499	188.67	92.995	3604.20
850	12000.0	7.816	15.632	191.94	93.796	3665.80
890	13000.0	8.027	16.055	202.46	96.333	3867.50
960	14000.0	8.228	16.457	212.72	98.739	4063.60
1,000	14620.0	8.348	16.696	218.95	100.179	4182.10
1,100	16000.0	8.602	17.204	232.48	103.228	4440.30
1,160	17000.0	8.778	17.557	242.11	105.334	4624.80
1,230	18000.0	8.947	17.895	251.57	107.371	4807.00
1,350	19000.0	9.110	18.220	260.74	109.323	4980.30
1,368	20000.0	9.267	18.554	269.81	111.208	5153.40

The following diagram (Fig. 101) illustrates the dirigible aërostat of M. Santos Dumont. It will be noted

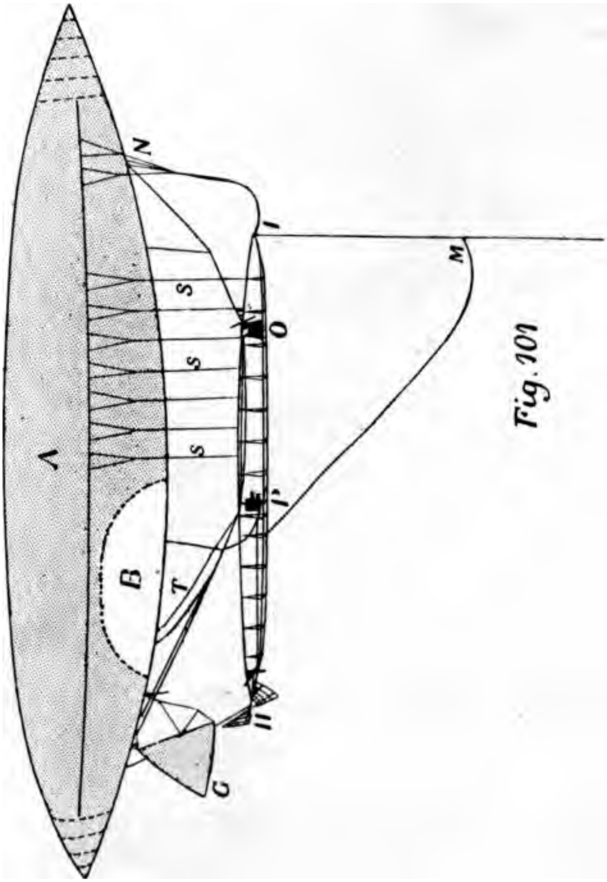

Fig. 101

that the structure is very light, and offers very little resistance to the air relatively to the power and buoyancy.

The aërostat A is pointed at each end, and an interior balloon or envelope B containing air is placed inside, and controlled from the motor P by a pipe T. This is the arrangement first adopted by Partridge in his "Pneumadrome," which is previously described. A trailing rope I,

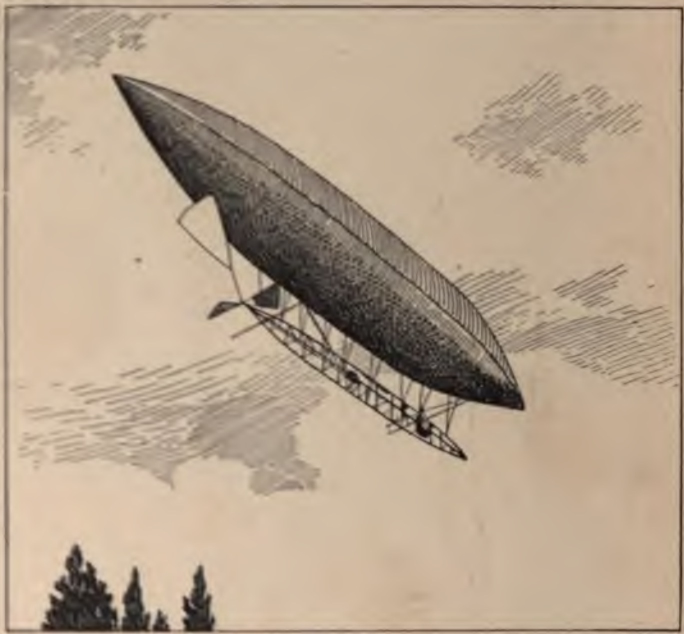

Fig. 102.

with a guide M, is provided, in addition to a rudder G. The aëronaut sits in a light wicker basket chair O, from whence he may control the mechanism. The engine P develops 16 H.P., and is actuated by the explosion of vaporised petrol. The screw propeller H is made with flexible rear edges, and at 150 revolutions per minute

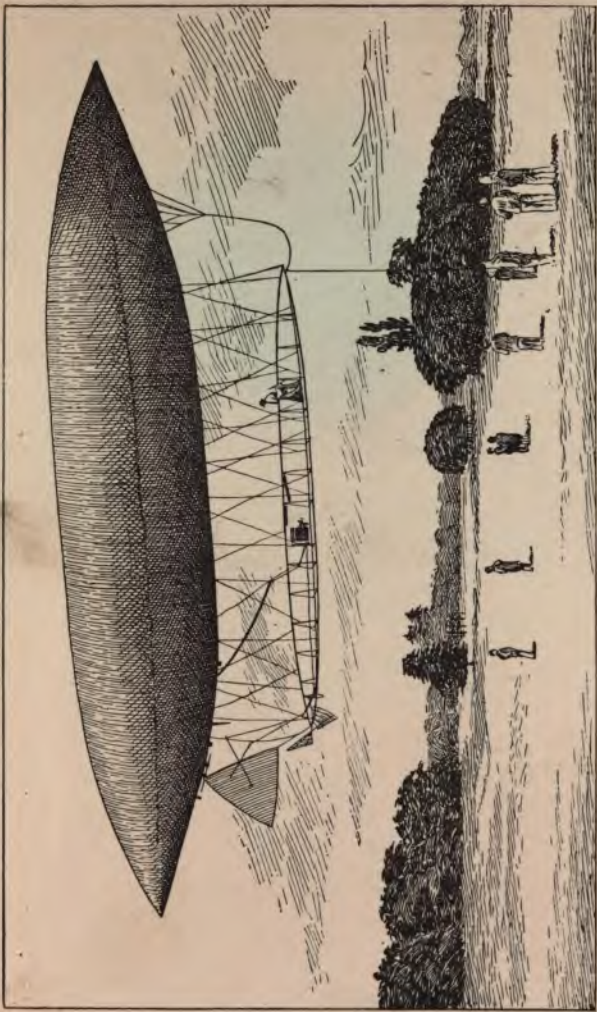

Fig. 103.

exerts a thrust of 60 lbs. The total weight of the apparatus is 550 lbs.

Fig. 102 shows the machine progressing against the wind, and Fig. 103 illustrates the start from the Parc d'Orient in the 15,000 franc competition, 13th July 1901,

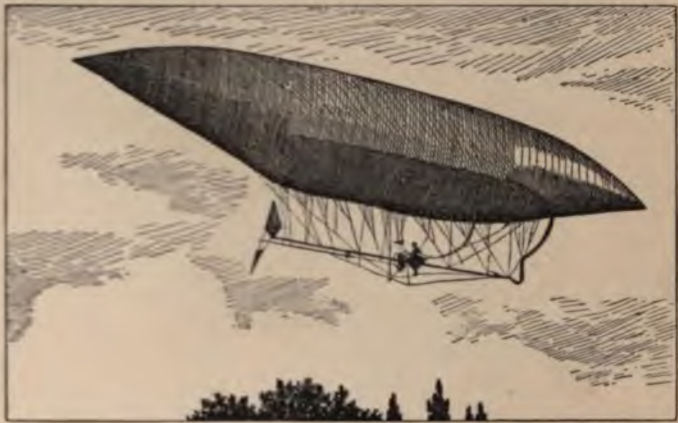

Fig. 104.

which, after some discussion, was awarded to M. Santos Dumont. Fig. 104 shows the progression of the aërostat against the wind. Fig. 105 (see Frontispiece) shows the aërostat rounding the Eiffel Tower during the competition.

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